NUMERICAL INVESTIGATION OF EFFECTIVE SURGE TANK DIMENSIONS IN HYDROPOWER PLANTS UNDER VARIOUS HYDRAULIC CONDITIONS

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ABSTRACT

NUMERICAL INVESTIGATION OF EFFECTIVE SURGE TANK DIMENSIONS IN HYDROPOWER PLANTS UNDER VARIOUS HYDRAULIC CONDITIONS

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In water conveyance systems, sudden changes in the flow velocity cause a phenomenon called waterhammer associated with high pressure head changes. Unless a control device is used as a precaution, waterhammer may result in costly damages and even in some cases, loss of human lives. In light of this concept, different control devices that can protect the systems against waterhammer are introduced so that the great pressure differences are absorbed and the system is maintained undamaged. The surge tank is one of those control devices.

In this thesis, the main functions, the requirements for its construction and the different types of the surge tanks are explained. The governing differential equations defining the flow conditions of the surge tanks and their solutions are provided. In addition, for the use of design engineers a procedure to determine proper dimensions of a surge tank is developed.

For the sake of dimensioning the surge tank effectively, empirical equations, which calculate the height of three different types of surge tanks with dimensionless parameters, are obtained. With the help of regression analysis, the correlation between the parameters of the developed equations are determined, and found to be relatively high. Finally, the economical aspect of a surge tank is discussed and comparison parameters are introduced to the designer.

Keywords: Surge Tank Design, Surge Analysis

ÖZ

HİDROELEKTRİK SANTRALLERDE ETKİN DENGE BACASI BOYUTLARININ ÇEŞİTLİ HİDROLİK KOŞULLAR ALTINDA NÜMERİK OLARAK ARAŞTIRILMASI

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Su iletim sistemlerinde, akım hızındaki ani değişimler yüksek basınç yükü değişimleriyle birlikte su darbesi denilen olaya sebep olur. Önlem olarak bir kontrol aracı kullanılmazsa, su darbesi pahalıya mal olan zararlarla hatta bazı durumlarda can kayıplarıyla sonuçlanabilir. Bu durum göz önünde bulundurulduğunda, basınç farklarını sönümleyebilen ve böylece sistemde stabilite sağlayabilen bazı araçlar sisteme eklenir. Bunlardan bir tanesi de denge bacasıdır.

Denge bacasının ana fonksiyonları, hangi durumlarda yapımının gerekli olduğu ve değişik tipleri bu tezde açıklanmıştır. Denge bacalarındaki akım koşullarını belirleyen diferansiyel denklemler ve bu denklemlerin çözümü verilmiştir. Ayrıca, tasarım mühendislerinin kullanımı için denge bacasının uygun boyutlarını belirlemeye yönelik bir metod geliştirilmiştir.

Denge bacasının etkin boyutlandırılması amacıyla üç farklı tip denge bacası için, boyutsuz parametrelerle, denge bacası yüksekliği hesaplayan formüller bulunmuştur. Regresyon analizi yardımı ile, parametreler arasındaki ilişkilerin derecesi belirlenmiş ve oldukça yüksek bulunmuştur. Son olaraksa, denge bacası tasarımı ekonomik açıdan da tartışılmış, ve tasarımcıya bazı kıyaslama parametreleri önerilmiştir.

Anahtar Kelimeler: Denge Bacası Tasarımı, Dalga analizi

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LIST OF SYMBOLS AND ABBREVIATIONS

a_w	Wave speed (m/s)
K	Bulk modulus of water (Pa)
ρ	Density of water (kg/m^3)
E	Elasticity modulus of pipe material (Pa)
D	Pipe diameter
c_1	A dimensionless parameter that describes the effect of pipe anchor on the wave speed. In case of pipes anchored with expansion joints throughout, this parameter can be taken as unity.
t	Wall thickness of the pipe (m)
T	Duration of the manoeuvre (s)
T_c	Critical time (s)
L_c	Length of penstock (m)
ΔH	Pressure head change (m)
g	Gravitational acceleration (m/s^2)
ΔV	Velocity difference in penstock (m/s)
L_i	Length of pipeline segments having different diameter (m)
V_i	Velocity of pipeline segments having different velocity (m/s)
H_n	Minimum net head (m)
S	Slope of energy grade line
V	Velocity in corresponding section (m/s)
n	Manning roughness coefficient
R	Hydraulic Radius of the section which is equal to flow area divided by the wetted perimeter of the section (m)
Δh_f	Head loss due to friction (m)
β_f	Modified friction loss coefficient
Δh_m	Head loss due to a minor loss (m)
K	A minor loss coefficient for the corresponding pipe element
D	Diameter of the smaller cross-section (m)
D	Diameter of the larger cross-section (m)
β_m	Modified minor loss coefficient
Δh	Head loss due to friction or minor losses
c	Modified coefficient of friction which is used in surge analysis (s^2/m^5)
β_t	Total coefficient of friction for tunnel
c_t	Modified coefficient of friction of tunnel which is used in surge analysis (s^2/m^5)
β_s	Total coefficient of friction for surge tank
c_s	Modified coefficient of friction of surge tank which is used in surge analysis (s^2/m^5)
A_s	Area of surge tank (m^2)
V_s	Velocity of main tank (m/s)
A_{sec}	Area of the section for which the losses are calculated (m^2)
V_{sec}	Velocity of the section for which the losses are calculated (m/s)
F	Minimum area of a surge tank required for stability (m^2)
L_t	Length of tunnel (m)
A_t	Area of tunnel (m^2)
V_t	Velocity of tunnel (m/s)
D_t	Diameter of tunnel (m/s)
β_{total}	Total modified coefficient of friction calculated from Equation (4.9) for the total head losses that occur in the system (s^2/m)
H_0	Net head on turbine
e	A safety coefficient which is generally taken as 1.5 ~1.8. However, Jeager(1955) proved that this factor should vary depending on the system properties
Y_{max}	The height of maximum upsurge for the case of maximum discharge, full load rejection and no friction in the tunnel (m)

Fr	Froude number
S	Submergence depth (m)
B	Height of the water column in the surge tank (m)
$Y_{maxdown}$	Height of maximum downsurge that is used in the vortex control (m)
P	Freeboard (m)
H_{resmax}	Maximum water elevation in reservoir (m)
H_{resmin}	Maximum water elevation in reservoir (m)
H_{tank}	Total surge tank height (m)
H_{shaft}	Height of shaft (m)
D_{tank}	Surge tank diameter (m)
D_t	Tunnel diameter (m)
D_{orf}	Orifice diameter (m)
D_{shaft}	Shaft diameter (m)
Q	Discharge of corresponding section (m^3/s)
Q_t	Tunnel discharge (m^3/s)
Q_s	Discharge into and out of the surge tank (m^3/s)
Q_{tur}	Turbine discharge (m)
y_{1max}	Height of maximum upsurge for the case of full load rejection when the system is working with full capacity and reservoir is at maximum water elevation (m)
y_{2max}	Height of maximum downsurge for the case of full load acceptance when the system is to be put into operation with full capacity and the reservoir is at maximum water elevation (m)
y_{2min}	Height of maximum downsurge for the case of full load acceptance when the system is to be put into operation with minimum capacity and the reservoir is at minimum water elevation (m)
Δt	Time interval (s)
Q_{max}	Maximum discharge in the tunnel (m^3/s)
Q_{min}	Minimum discharge in the tunnel (m^3/s)
ν	Kinematic viscosity of water (m^2/s)
μ	Dynamic viscosity of water (Ns/m^2)
c_{orf}	Modified coefficient of head loss for orifice (s^2/m^5)
c_{shaft}	Modified coefficient of head loss for shaft (s^2/m^5)
$H_{main\ tank}$	Main tank height (m)
r^2	Coefficient of determination
d	Thickness of concrete lining (m)
$D_{main\ tank}$	Diameter of main tank of a shafted surge tank (m)
C_{ex}	Unit cost of excavation (TL)
C_{fwork}	Unit cost of formwork (TL)
C_{co}	Unit cost of concrete (TL)
C_{re}	Unit cost of reinforcement (TL)

CHAPTER 1

INTRODUCTION

Hydropower, nowadays, is a popular source of renewable energy. It enables low operation costs as the cost of fossil fuels are eliminated throughout the operation life of a hydroelectric power-plant. In addition, hydropower can adapt to varying demands of energy, which brings its advantage of flexibility. Also, it is used as a storage with the reservoir that is present in dams. Lastly, its suitability for some industrial purposes and the reduced amount of carbon dioxide emission explains the advantages of hydropower more deeply.

The production of energy without failures or delays during the operation of a hydropower plant is very crucial. Steady state operation, in which the hydraulic variables of the system, like discharge or pressure heads, do not change with time, can satisfy this kind of energy production. However, some disturbances may occur in the system resulting in the change of the state of the flow that is being turbined. Therefore, the hydraulic variables of the system start to change with time. This type of flow regimes are called hydraulic transients or waterhammer.

Waterhammer results in extremely high or low pressures in the system. These extreme changes of pressure if not prevented can cause severe damages like the failure of turbines, the penstock or the collapsing of the entire system resulting in environmental tragedies with human losses. The accident that occurred in Sayano-Shushenskaya Hydroelectric Dam in Russia, 2009 would be a good example to explain the significance of waterhammer accidents. The failure of one of the turbines of the system triggered the whole system to collapse resulting in the death of 75 people. This single event points out the importance of controlling the phenomena of waterhammer.

In order to control the extreme pressure changes caused by hydraulic transients in a system, some devices are introduced into the system. Surge tank is one these controlling devices. It is an open or close standpipe, with the types simple, restricted orifice, shafted and differential. In addition, it is called an air chamber if pressurized air is also present within the tank above the water surface. Surge tank absorbs the extreme pressures, which are caused by the hydraulic transients in the system. In addition, it acts like a storage tank and supplies water to the system when needed. Therefore, it also helps to regulate the flow passing through turbines resulting in an effective operation.

As every system is unique with its environmental and hydraulic conditions, the appropriate dimensioning of the surge tank should be done with great care. The dimensions, which give the best functioning of the tank with a suitable economy should be selected. That being said;

In Chapter 2, literature survey is given. Previous studies on mass oscillations for different types of surge tanks, the dimensioning and the design considerations throughout this process are explained.

In Chapter 3, the concept of water hammer is discussed briefly. The causes and the calculations related to the phenomena are described. In addition, the types and functions of a surge tank are briefly explained.

In Chapter 4, the procedure to be followed throughout the dimensioning process of a surge tank, the limiting conditions of the system, the models and the governing differential equations for each type of surge tank and the solutions of these differential equations are given in detail. In addition, the procedure to be followed for the determination of the height of a surge tank is explained.

In Chapter 5, a dimensional analysis is carried out. Then, empirical equations are developed to calculate the effective tank heights for different types of surge tanks.

In Chapter 6, case studies are done with the developed equations. With the help of regression analysis, the correlation between the parameters of the developed equations are determined. The differences among them are discussed.

In Chapter 7, financial considerations about surge tanks are discussed. Alternative ways for obtaining comparison parameters are investigated. Some parameters, that allow the designer to dimension a surge tank in a way that it functions well and costs less, are suggested.

Finally, in Chapter 8 conclusions and future recommendations are presented.

CHAPTER 2

LITERATURE SURVEY

The studies conducted up to now, which helped form the basis of this thesis are briefly summarized in this chapter in a chronological order.

Frizell (1895) carried out the first waterhammer study in a hydropower facility. He was able conduct his experiments as he was working as an engineer in Ogden Hydropower Plant in Utah. The derivation of the equations, for a pressure increase for the case of sudden stoppage, was conducted by him.

Joukowsky (1897) is known for developing the basic waterhammer theory. He tested systems of different diameters and lengths which allowed him to transfer his experimental and theoretical work, into a theory. The wave velocity in which the elasticity of the system is included, the definition of the critical time during a transient, the proportion between the decreased flow velocity and the increased pressure are all of his study areas. In addition to all his work, he also discussed how the surge tanks, air chambers and valves effect the pressures created during transient states of flows.

Allievi (1902), based on the dynamic equation with a higher accuracy and the new derived dimensionless parameters, is known as the publisher of the general theory of waterhammer. The uniform valve manoeuvres, their durations and the corresponding increased pressures also cover his study areas.

Thoma (1910) studied the stability of a surge tank for the case of "constant power". The concept is to obtain a constant power input or an output through the turbine. It is concluded that the fluctuations are stable if the surge tank area is greater than a minimum value, which is called the "Thoma area" now.

Braun (1910) also studied the concept of waterhammer and published similar equations to the ones that Allievi presented for the general theory of waterhammer. In addition, he conducted analysis on surge tanks. He proposed a formula for the calculation of the height of maximum downsurge for a load acceptance from the turbine.

Frank and Schüller (1938) studied the stability of the oscillations in surge tanks. They derived conclusions for two different particular cases. First case called the "constant flow", is the variation of the turbined discharge from one value of discharge to another and these values of discharges correspond to the steady-state values. Second case called the "constant-gate opening", is the combination of some particular cases like, the full gate opening due to a sudden load increase, in which the positioning of the gate remains constant. It is concluded that, for the first case the fluctuations are always said to be stable in the presence of frictional losses and for the second case the fluctuations are always stable. In addition, Frank derived the formula for calculating the height of maximum downsurge for the case of instantaneous partial load acceptance from a turbine.

Creager and Justin (1950) investigated the concepts of waterhammer and surge tanks. They discussed the behavior of different types of surge tanks such as the simple, restricted orifice and differential surge tanks by comparing the height of maximum upsurge and downsurges that occur in the systems. They carried out a surge analysis by means of Johnson's charts for both load rejection and acceptance cases and designed the surge tank.

C. Jaeger (1953) studied the mass oscillations within a surge tank. Different types of surge tanks, especially the ones connecting to underground hydropower facilities are discussed together with some additional remarks on their stability. The conditions of loading, which makes up the worst case scenarios in a system, are revised. In addition, a revision is conducted about the basic assumptions of different engineers on the basic differential equations of surge analysis. It is concluded that, there exists an agreement on the basic concepts of the surge analysis theory in spite of some differences caused by some exceptional cases.

C. Jaeger (1955) carried out analysis on surge tanks, in which he proposed a formula that calculates the height of the maximum upsurge for a sudden load rejection from the turbine. In addition, he investigated the stability criterion proposed by Thoma and found out that the coefficient of safety used within the formula of the Thoma area, can not be taken as constant and he proposed another formula for the calculation of the safety coefficient.

Parmley (1958) developed a computer program that conducts surge analysis. The dynamic and the continuity equations governing the surge analysis are transformed into non-dimensional ones. The Runge-Kutta method is used for the solution of the differential equations. The program is able to carry out the surge analysis for different types of surge tank, located either upstream or downstream of the system.

Marris and Sideriades (1959), by means of the phase-plane method, concluded that the stability area proposed by Thoma does not hold for surge tanks having large fluctuations within.

Wei (1963) conducted a study about the stability criterion for a simple surge tank. First, he carried out his analysis based on maintaining constant power output from a turbine, which was the common conception considered those days. With his results, he revised the stability formula of Thoma. However, he found out that, when the rated head of the turbine becomes higher than the head of the system following a maximum downsurge then, the stability analysis should be based on maintaining a constant gate opening for the turbine. He investigated three different load demand cases based on these concepts and concluded that, there exists a significant influence of rated head on stabilizing the fluctuations in a simple surge tank.

Pickford (1969) also dealt with waterhammer theory and surge control. He conducted graphical analysis for the calculation procedure of different types of manoeuvres. In addition, he also studied surge tanks. He managed the solution of the fundamental equations of mass oscillations in a surge tank by means of finite difference methods. Ruus (1969) concluded that the critical case to be investigated for the stability of the fluctuations within a surge tank is created by smaller oscillations rather than larger ones.

Mosonyi and Seth (1975) were the first to carry out the surge analysis of a restricted orifice surge tank. In a German laboratory with the operation of a restricted orifice tank, they developed the governing equations based on the existence of a significant pressure head increase in magnitude in the penstock upstream of the surge tank.

Arshenevskii et all (1984) offered a method for the optimization of the design parameters of different types of surge tanks, mainly the differential and the restricted orifice surge tank. The method proposed is based on eliminating a design parameter at every step. When one parameter is taken as constant and the others vary, it offers the opportunity to the designer to choose the correct group of data. At every step, a parameter is chosen according to some boundary conditions predetermined. At the end, the group of parameters, which will give the minimum cost for a surge tank would be obtained.

Chaudhry (1987) is known with the inclusion of the pipe wall elasticity and the water compressibility of a water column in transient effects. He conducted the verification of a computer simulation based on his derivation of an analytical stability criterion. The surge tanks were also his study area. He studied the mass oscillations and the design of surge tanks based on Johnson’s charts. In addition, with Ruus (1969), they investigated the stability of the fluctuations within a surge tank by means of the phase-plane method for four different cases as; constant flow, constant-gate opening, constant power and constant power combined with full-gate opening.

Moghaddam (2004) developed an optimization function, in which the objective function is to minimize the cost of a system consisting of a conduit and a simple surge tank. The derivation of the basic surge analysis equations are carried out. After this derivation, the equations are rewritten in dimensionless form enabling the construction of the objective function. By means of trial and error, the function is optimized and the diameter of the conduit and the simple surge tank, which minimizes the cost of the facility are obtained.

Kendir (2006) presented a study, which investigates the optimum form of a surge tank theoretically and experimentally in a hydroelectric facility. The surge analysis is carried out by finite differences method for each type of surge tank theoretically. Then, a prototype is constructed and surge analysis is carried out to obtain the corresponding experimental results. It is concluded that the optimum form of a surge tank is a V shaped tank.

Moharrami et all (2008) conducted the optimization of a differential surge tank, in which the objective function is to minimize the total cost of a differential surge tank. The Barrier method is used throughout the derivation of the method. The height of the tank, the diameter of the main tank, the diameter of the riser and the diameter of the orifices are the outputs of the optimization problem. To verify the accuracy of the optimization method developed, a case study is carried out for the surge tank of the Appalachia dam.

Lika (2008) studied the mass oscillations in throated surge tanks. A prototype is used to test different sized surge tanks with different sized throats in a laboratory environment. The experimental results were then compared with theoretical ones concluding, the finite difference method is appropriate to use throughout the surge analysis calculations. In addition, surge tanks having larger tank diameters should be used in the design processes rather than the ones having smaller diameters because the large diameters functions better than the smaller ones.

Nabi et all (2011) carried out a surge analysis for surge tanks with and without chambers. Their aim is to find out whether the surge tanks with more chambers function better than the non-having or single having ones. Under the light of this purpose, they carried out a case study for two hydropower plants in Pakistan. Surge analysis is carried out for each of the hydropower plants, the surge heights and their corresponding time of dissipations are verified. As a result, it is concluded that, the surge tanks having more than one or none chambers function better when compared to the other types based on the observation of lower surge heights and therefore stability.

CHAPTER 3

WATER HAMMER AND SURGE TANKS

In this chapter, the concepts of waterhammer, pressure difference calculations, the effect of waterhammer on the whole system are explained. Then surge tank as a control device, the reasons to use a surge tank and its types are presented.

3.1 Concept of Waterhammer

A flow is said to be steady, if the flow conditions of a system do not vary with time at a point. However, if the flow conditions vary with time at a point, the flow is said to be unsteady. The state of flow in which the flow conditions of a system vary from one steady state to another is termed as transient flow.

Waterhammer, in which the flow is said to be in transient state, is the fluctuation of the pressure head of a system due to sudden changes in the rate of flow. Depending on whether there is a load demand or load rejection the hydraulic gradient of the system fluctuates up and down until the excessive pressure is damped out by friction.

If there is a load rejection;

The turbine gate starts to close to meet the conditions of the new load demand therefore the flow passing through the turbines is reduced by some amount. Consequently, the pressure at the turbine is raised resulting in the hydraulic gradient of the system to change from AJ to AB until the gate movement is completed. After the closure of the gate is finished, the hydraulic gradient starts to swing between AB and AC, until the fluctuation of the water is damped out by friction and the excessive pressure change is dissipated. (Figure 3.1).

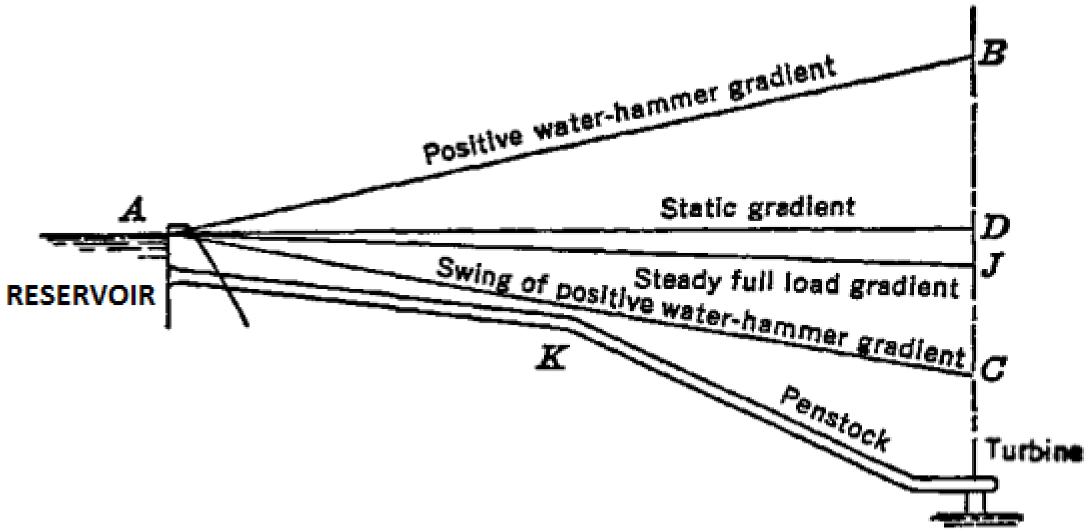

Figure 3.1 Change in hydraulic gradient with positive water hammer (Creager & Justin, 1950)

If there is a load acceptance;

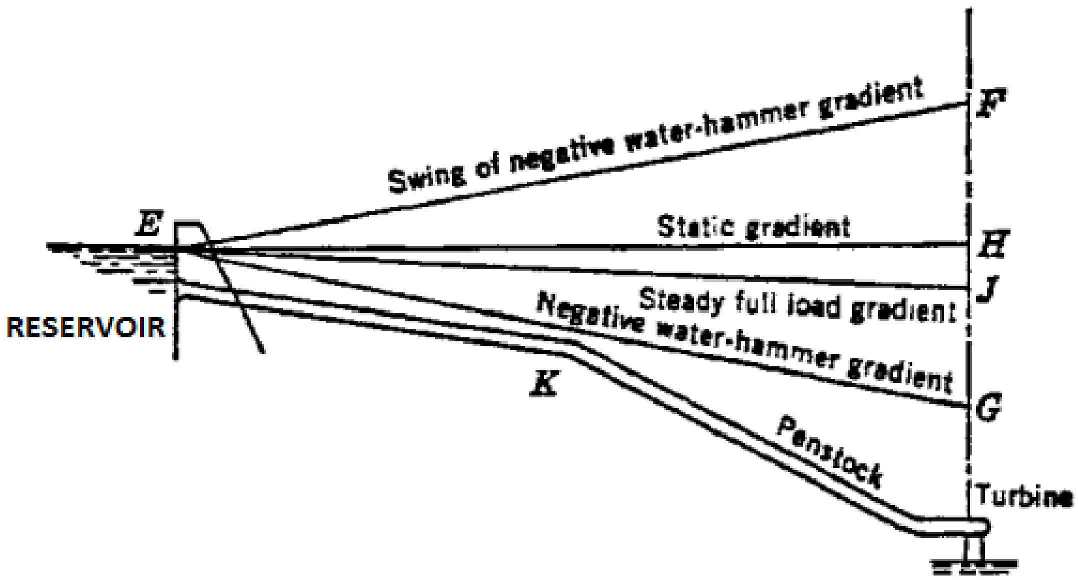

Figure 3.2 Change in hydraulic gradient with negative water hammer (Creager & Justin, 1950)

The turbine gate starts to open to meet the conditions of the new load demand therefore the flow passing through the turbines is raised by some amount. Consequently, the pressure at the turbine is dropped resulting in the hydraulic gradient of the system to change from EJ to EG until the gate opening is completed. After the gate movement is finished the hydraulic gradient starts to swing from

EG to EF until the fluctuation of the water is damped out by friction and the excessive pressure is dissipated. (Figure 3.2).

3.2 Waterhammer Calculations

3.2.1 Calculation of the wave speed, a_w

When a pressure rise or drop develops by the movement of a pipe element such as a valve, a turbine or a pump, a pressure wave starts to propagate back and forth between the reservoir or the forebay and the turbine through the conduit and the penstock. This wave speed, a_w, is expressed as (Wylie et al.,1993) ;

$$a_w = \sqrt{\frac{\frac{K}{\rho}}{1 + \frac{K}{E}\,\frac{D_p}{t}\,c_1}} \qquad (3.1)$$

Where, K : Bulk modulus of water (Pa),

ρ : Density of water (kg/m^3)

E : Elasticity modulus of pipe material (Pa),

D_p : Pipe diameter (m),

c_1 : A dimensionless parameter that describes the effect of pipe anchor on the wave speed. In case of pipes anchored with expansion joints throughout, this parameter can be taken as unity.

t = Wall thickness of the pipe (m)

3.2.2 Calculation of the pressure head change, ΔH

The calculation of a pressure head change caused by waterhammer depends on the duration of the manoeuvre, which is classified as sudden or gradual. A manoeuvre is said to be rapid if $T < T_c$ and it is said to be gradual if $T > T_c$.

Where, T = duration of the manoeuvre (s)

T_c = critical time (s).

T_c, critical time is calculated from Equation (3.2) as;

$$T_c = \frac{2L_c}{a_w} \quad 3.2$$

Where, L_c = length of penstock (m),

a_w = wave speed (m/s).

If a manoeuvre is said to be rapid then the pressure head change, ΔH is calculated (Joukowski, 1897) as;

$$\Delta H = -\frac{a_w}{g}\Delta V \quad 3.3$$

Where, ΔH = pressure head change (m),

a_w = wave speed (m/s),

g = gravitational acceleration (m/s^2),

ΔV = velocity difference in penstock (m/s).

It is obvious that, if the valve is closed suddenly, as the velocity difference, ΔV will be negative, the pressure difference, Δh will be positive. Similarly, if the valve is opened suddenly, as the velocity difference, ΔV will be positive, the pressure head change, ΔH will be negative.

It is obvious that, if the valve is closed gradually, as the velocity difference, ΔV will be negative, the pressure head change, ΔH will be positive. Similarly, if the valve is opened gradually, as the velocity difference, ΔV will be positive, the pressure head change, ΔH will be negative

As a result, waterhammer should be considered while designing a pipe system because it creates greater pressure differences than the ones that are created when the system is operating in steady-state.

To reduce the pressures created by waterhammer, some control devices are introduced in the system. Surge tank is one of these control devices. The uses, the effects of it on the system will be explained in detail in Section (3.3).

3.3 Surge Tank

A surge tank is a shaft or an open standpipe, generally connected to the fluid system between the conduit and the penstock. The main functions of a surge tank are;

When there is a load rejection at the turbine, a positive waterhammer pressure head is created immediately on the turbine. This pressure wave starts to propagate from the turbine until it reaches to the surge tank. When the pressure wave enters to the surge tank it fluctuates in the tank until it is damped out by the friction that exists in the tank.

Similarly, when there is a load acceptance at the turbine, there is an immediate need for extra water to satisfy the new demand conditions, but the water coming from the reservoir can not accelerate that fast. As a result, surge tank acts like a storage and the needed amount of water is provided from the tank, which can accelerate in the desired manner with the steeper slope of the penstock.

In addition to these;

The pressure waves created in the system propagate between the turbine and the nearest surface, which is open to the atmosphere. Unless there is a surge tank, the nearest surface that is open to the atmosphere is the reservoir. However, if there is a surge tank, the pressure wave propagates between the turbine and the surge tank. Therefore, the length of the pipeline that needs to withstand the waterhammer pressure is shortened.

An effective power generation depends on a regulated discharge passing through the turbine. The more the turbine discharge is regulated, the more effective the power generation is. Surge tank provides the regulation of the turbine discharge with the capability of responding the system needs immediately like providing the amount of water needed during a load acceptance.

3.3.1 System Conditions that Require a Surge Tank

The system conditions that require a surge tank are (Chaudhry, 1987) ;

If the total cost of the project that contains only penstock to resist the waterhammer pressure itself, is greater than the total cost of the project that contains both a penstock, which resists the reduced waterhammer pressure and a surge tank.

If ;

$$\frac{\mathrm{L_i V_i}}{\mathrm{H_n}} > 3 \text{ to } 5 \quad \text{SI units} \qquad 3.4$$

Where, L_i = Length of pipeline segments having different diameter (m),

V_i = Velocity of pipeline segments having different velocity (m/s),

H_n = Minimum net head (m)

The term, $\sum L_i V_i$, should be calculated from intake to the turbine.

If the maximum speed rise can not be decreased less than 60%, when one unit is in operation with maximum turbine output and there exists a sudden complete load rejection.

3.3.2 Types of Surge Tanks

According to their configuration;

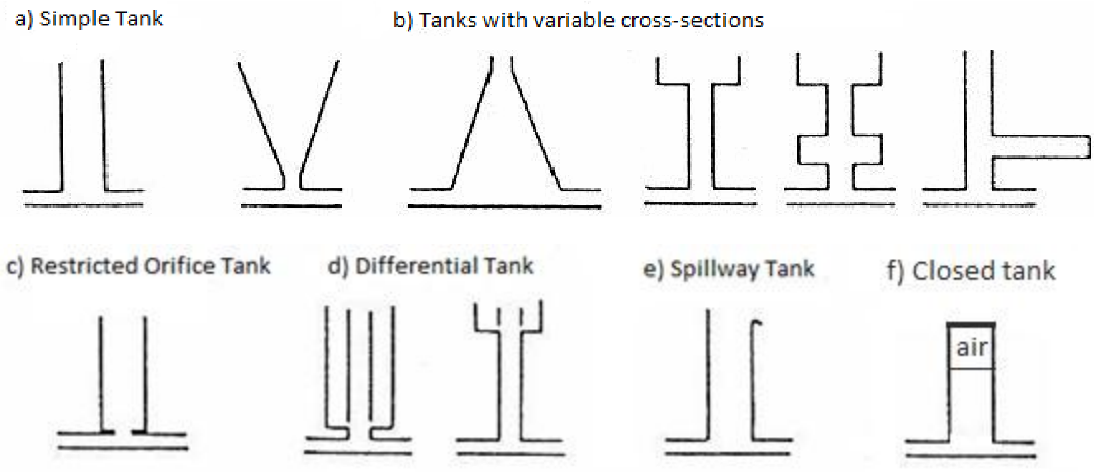

Figure 3.3.continued Types of surge tanks according to their configuration (Pickford, 1969)

There exists several types of surge tanks as simple, restricted orifice, differential, spillway and closed tanks all of which have advantage and disadvantages.

To start with, a simple surge tank is a tank, which is connected directly to the conduit with constant cross-section throughout (Figure 3.3a). Therefore, the head losses that occur in this type of tank is the smallest among all types. This is why it damps the surges created by waterhammer slower compared to other types. In addition, because of the small head losses, the amplitude of the surges are greater, therefore it needs to be designed higher in order to prevent an overflow. This is why it is the least economical among all types.

In a restricted orifice surge tank there exists an orifice at the entrance of the tank (Figure 3.3c). Some energy is lost while the water passes through it, which results in the reduction of the surge amplitudes. Moreover, because of its restrictive effects the volume of the inflow and the outflow through the tank is decreased. Therefore, the height and size of the tank is also reduced. However, the area of the orifice needs to be selected with care because if it is too small, then the inflow and the outflow through it will be prevented, if it is the same with the area of the tunnel then the head loss through it would be an amount that could be neglected, therefore the orifice is useless.

There also exist some drawbacks of this type of tank. The restrictive effects of the orifice, results in the transmission of some of the waterhammer waves to the conduit. In addition, the rapid development of the accelerating and the decelerating heads has a negative effect on turbine regulation.

A differential surge tank is a combination of a restricted orifice and a simple surge tank (Figure 3.3d). The internal riser acts like a simple tank, where the outer tank acts like a restricted orifice one. This is why the differential tank responds to sudden changes in the system slower than the restricted orifice tank but faster than the simple tank. And because of the same reason, it has a less negative effect on turbine regulation compared to restricted orifice tank.

In a spillway tank, a spillway is provided in order to control the height of the tank (Figure 3.3e). When the water fluctuates in the tank, the extra amount of water is thrown by means of the spillway. This way the size of the tank can be reduced and the tank can be constructed in the desired way. However, the water that is thrown away sometimes needs to be transported unless another place is provided. This transportation can be expensive which turns the advantage of providing a spillway in a tank into a disadvantage.

A closed surge tank, which is also named as the air chamber, contains pressurized air within (Figure 3.3f). By the expansion and the contraction of the air inside the tank, the level of the surges are controlled and damped.

CHAPTER 4

DETERMINATION OF THE DIMENSIONS OF A SURGE TANK

In this chapter, the procedure for determining the dimensions of a surge tank will be explained in detail. In general, the model of each type of surge tank, the governing differential equations of surge analysis and the mathematical method used for solving these equations will be given.

4.1 Procedure Used for Calculations

Before giving detailed information for each type of surge tank, the general procedure will be given step by step.

First, the system information that already exists is gathered. These are;

- Maximum water level in reservoir
- Minimum water level in reservoir
- Maximum tunnel discharge
- Minimum tunnel discharge
- Tunnel length
- Tunnel diameter
- Slope of tunnel

Second, the initial conditions of the system are determined according to the type of disturbance in the system. For example, for a total rejection of load, discharge in the tunnel is taken as the maximum discharge whereas turbine discharge is taken as zero.

Third, a surge tank diameter is assumed. In addition, an orifice diameter for a restricted orifice surge tank or a shaft diameter for a shafted surge tank are also assumed.

Forth, the friction coefficients of tunnel, surge tank, orifice and shaft are calculated.

Fifth, surge analysis is carried out by the solution of the governing differential equations of the system by means of a mathematical method called the third order Runge-Kutta. Therefore, the values of maximum upsurge and downsurge for minimum and maximum discharges are obtained.

Consequently, height of the surge tank to the corresponding assumed diameters is determined.

4.2 Limiting Conditions

4.2.1 Head Losses

Lots of head losses arise when the system is under operation. Even the fluctuations that occur in the surge tank are damped with head losses. Therefore, head loss calculations should be done with great care in order to obtain accurate results.

Friction losses and minor losses are the ones that occur when the system is under operation. Therefore, general formulae used for the calculation of these losses are explained in the following sections.

4.2.1.1 Calculation of Head Losses due to Friction

Calculation of head losses due to friction, is performed according to the Manning's formula (4.1);

$$V = \frac{1}{n} R^{2/3} S^{1/2} \qquad (4.1)$$

Which can be reorganized as (4.2) ;

$$S = \frac{V^2 n^2}{R^{4/3}} \qquad (4.2)$$

Where S = Slope of energy grade line,

V = Velocity in the section (m/s),

n = Manning roughness coefficient,

R = Hydraulic Radius of the section which is equal to flow area divided by the wetted perimeter of the section (m).

When (4.2) is multiplied by L, the tunnel length, from both sides,

$$SL = \frac{Ln^2}{R^{4/3}} V^2 \qquad (4.3)$$

Head loss due to friction, $\Delta h_f = SL$, is obtained from (4.3) .

In order to simplify the calculations, β_f is defined;

$$\beta_f = \frac{L}{k^2 R^{4/3}} \qquad 4.4$$

Where, $k = 1/n$.

β_f = Modified friction loss coefficient

4.2.1.2 Calculation of Minor Losses

Typical minor losses that arise when the system is in operation are due to the pipe elements such as bends, sudden contraction and sudden expansion of the cross-sections suddenly. These losses are calculated from Equation (4.5) (White, 2004);

$$\Delta h_m = K \frac{V^2}{2g} \qquad 4.5$$

Where, Δh_m = Head loss due to a minor loss (m),

K = A minor loss coefficient for the corresponding pipe element,

V = Velocity in the section (m/s),

g = Gravitational acceleration (m/s^2).

The velocity while calculating the minor losses both for contraction and expansion is taken as the velocity of the section with smaller cross-section.

The minor loss coefficient K, is taken as 0.5 where there is an entrance into the tunnel from reservoir.

For other losses due to varying cross-sections it is calculated as;

If there is a contraction (White,2004);

$$K = 0.42\left(1 - \left(\frac{d}{D}\right)^2\right) \qquad 4.6$$

Where, d = Diameter of smaller cross-section (m),

D = Diameter of larger cross-section (m),

If there is an expansion (White,2004);

$$K = \left(1 - \left(\frac{d}{D}\right)^2\right)^2 \qquad 4.7$$

Where, d = Diameter of smaller cross-section (m),

D = Diameter of larger cross-section (m).

After minor loss coefficient, K, is calculated, it is modified to Equation (4.8) in order to make it appropriate to be used in the differential equations of surge analysis.

$$\beta_m = \frac{K}{2g} \qquad 4.8$$

Where, β_m= Modified minor loss coefficient

g = Gravitational acceleration (m/s^2).

4.2.1.3 Addition of Head Losses to the Differential Equations

The head loss due to friction or minor losses Δh can be calculated from Equation (4.9);

$$\Delta h = \beta V^2 \tag{4.9}$$

However, head losses are found in the form of Equation (4.10) in the governing differential equations of surge analysis.

$$\Delta h = cQ^2 \quad 4.10$$

Where, c = Modified coefficient of head loss which is used in surge analysis (s^2/m^5),

Q = Discharge of the system (m^3/s).

All of the β_f and β_m values that correspond to the head losses in tunnel are all summed up and β_t, which is the total coefficient of head loss for tunnel, is obtained. Therefore substituting Equation (4.9) into Equation (4.10) for head losses in tunnel results in;

$$c_t = \frac{\beta_t}{A_t^2} \quad 4.11$$

Where, A_t = Area of tunnel

c_t = Modified coefficient of head loss for tunnel which is used in surge analysis.

Similarly, all of the β_f and β_m values that correspond to the head losses in surge tank are all summed up and β_s, which is the total coefficient of head loss for surge tank, is obtained. Substituting Equation (4.9) into Equation (4.10) for head losses in surge tank results in,

$$c_s = \frac{\beta_s}{A_s^2} \quad 4.12$$

Where, A_s = Area of surge tank

c_s = *Modified coefficient of head loss for surge tank which is used in surge analysis.

For minor loss calculations, β_m should be multiplied by the velocity of the section with smaller diameter. However, in order to be substituted into the differential equations β_m should be multiplied with the velocity of the main tank. Therefore, the velocities of those sections should be converted into the velocity of the main tank by Equation (4.13);

*c_s is termed as c_{orf} for a restricted orifice surge tank and c_{shaft} for a shafted surge tank.

From continuity;

$$Q = A_s V_s = A_{sec} V_{sec}$$

$$V_{sec} = \frac{A_s V_s}{A_{sec}}$$

$$V_{sec}^2 = \frac{A_s}{A_{sec}} V_s^2 \qquad 4.13$$

Where, Q_s = Discharge into or out of tank (m^3/s),

A_s = Area of main tank (m^2)

V_s = Velocity of main tank (m/s),

A_{sec} = Area of the section for which the losses are calculated (m^2),

V_{sec} = Velocity of the section for which the losses are calculated (m/s).

β_s is the same for the flow into and out of the tank. Therefore, the same coefficients are taken throughout the calculations for inflow and outflow.

4.2.2 Stability Criteria

In order to classify a surge tank as stable;

- First, it should be able to dampen the fluctuations and obtain a stable level within immediately.
- Second, there should not be any vortex problem threatening the system.

4.2.2.1 Minimum Area of a Surge tank

When there is a disturbance in the system, causing the water in the surge tank to fluctuate, these fluctuations are classified as stable or unstable. When the fluctuations are damped in a reasonable time then they are said to be stable. However, if their amplitude is increasing with time or they are not damped in a reasonable time, the fluctuations are said to be unstable.

In order to have this kind of stability in a surge tank, the tank should satisfy the minimum area requirement, which is called the Thoma Area (Thoma, 1910) and is calculated from Equation (4.14);

$$F = e \frac{L_t A_t}{2g\beta_{total} H_0} \qquad 4.14$$

Where, F =Minimum area of a surge tank required for stability (m^2),

L_t= Length of tunnel (m),

A_t =Area of tunnel (m^2),

g = Gravitational acceleration (m/s^2),

β_{total} = Total modified coefficient of friction calculated from Equation (4.9) for the total head losses that occur in the system (s^2/m),

H_0 = Net head on turbine (m),

e = A safety coefficient which is generally taken as 1.5 ~1.8. However, Jeager(1955) proved that this factor should vary depending on the system properties.

The formula that is proposed for the determination of this coefficient is (Jeager,1955);

$$e = 1 + 0.482 \ \frac{Y_{max}}{H_0} \qquad 4.15$$

Where, H_0 = Net head on turbine (m),

Y_{max} = The height of maximum upsurge for the case of maximum discharge, full load rejection and no friction in the tunnel (m). For the determination of the value Y_{max} in Equation (4.15), the following expression given in Equation (4.16) is used.

$$Y_{max} = V_t \ \left(\frac{L_t A_t}{g A_s}\right)^{1/2} \qquad (4.16)$$

Where, V_t = Velocity in tunnel (m/s),

L_t = Length of tunnel (m),

A_t = Area of tunnel (m^2),

g = Gravitational acceleration (m/s^2),

A_s = Area of surge tank (m^2).

4.2.2.2 Vortex Control

When a surge tank is in operation, due to a sudden disturbance like a valve manoeuvre etc. in the system, water level in the tank can fall under a certain elevation. If it does, air enters into the system. This may result in cavitation problem if air bubbles are carried by the flow into the turbine region and causes other negative effects threatening the system. Therefore, in order to avoid the air entrainment, a vortex control should be done for the worst case scenario that can occur in the system.

The worst case scenario for this kind of check generally occurs when there is a full load acceptance. The initial system conditions can either be minimum water level in reservoir and minimum discharge in tunnel or maximum water level in reservoir and maximum discharge in tunnel.

Therefore;

- First, the maximum downsurge that creates the minimum water level in the tank is calculated.
- Second, the bottom elevation of the tank is subtracted from the minimum water surface elevation in the tank. The height of water column in the tank is obtained (Water column height calculations are proceeded regardless of the type of the surge tank.).
- Then Froude number is calculated by Equation (4.17) ;

$$\mathrm{Fr} = \frac{\mathrm{V}}{\sqrt{\mathrm{gD}}} \qquad 4.17$$

Where, V = Velocity in tunnel (m/s),

g = Gravitational acceleration (m/s^2),

D =Diameter of tunnel (m).

- Using the Froude number, S/D value is obtained from Figure (C.1) in Appendix C. (Pickford, 1969)
- From this ratio, S, which is termed as the submergence depth, is obtained.
- If S is smaller than the height of the water column in the tank, then the system is said to be safe for vortex formation.

In addition to the vortex formation check, the system should also be checked if;

$$B > 0.2\ Y_{maxdown} \qquad 4.18$$

Where, B = Height of the water column in the surge tank, which is obtained by the subtraction of the bottom elevation of the surge tank from the minimum water elevation in the tank that can occur (m),

$Y_{maxdown}$ = Height of maximum downsurge that is used in the vortex control. (m).

4.2.3 Freeboard

For the sake of safety, a value, termed as freeboard is added to the predetermined maximum water elevation in the tank. Freeboard is calculated from Equation (4.19);

$$P = 0.2Y_{max} \qquad 4.19$$

Where P = Freeboard (m),

Y_{max} = is the height of maximum upsurge for the case of maximum discharge, full load rejection and maximum water level in reservoir (m).

4.3 Types of Surge Tanks

In this section, models, governing differential equations used in the mathematical method of solution are given for each type of surge tank. In addition, detailed procedure of the determination of tank height will be explained.

The derivation of the governing equations are performed with the following assumptions;

- The liquid is incompressible and the walls of the conduit are not deformable. Therefore the liquid in the conduit moves like a solid slug, transmitting a flow change throughout the system.
- The inertia of water in the tank can be neglected because it is small compared to the one in the tunnel.
- During transient state, head losses in the system can be computed using steady-state equation.

4.3.1 Simple Surge Tank

Three different models indicating three worst case scenarios that the calculations are based on are presented in Figures (4.1) to (4.3) respectively.

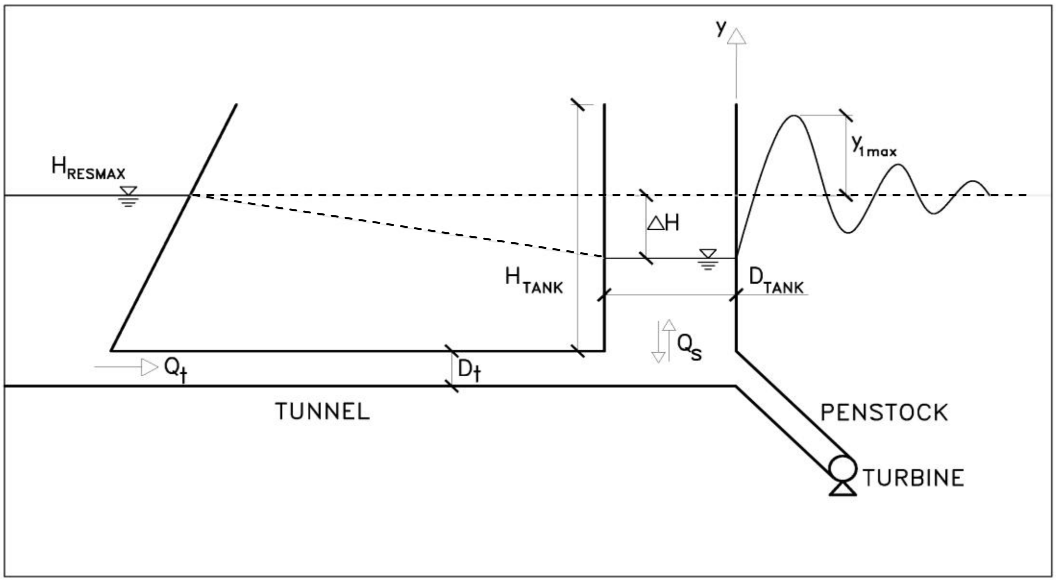

Figure 4.1 Full load rejection with maximum discharge for a simple surge tank

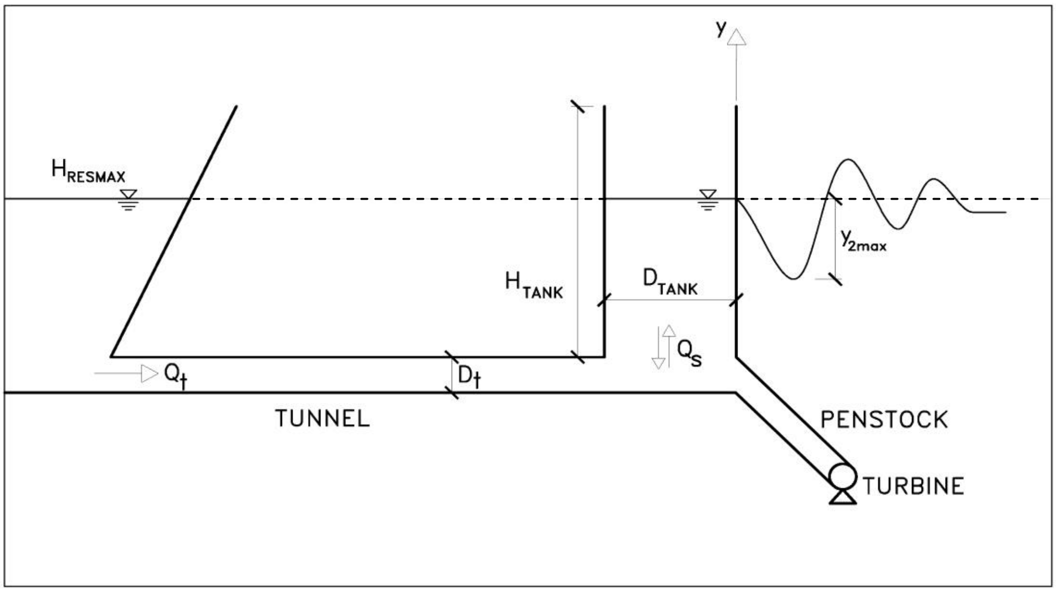

Figure 4.2 Full load acceptance with maximum discharge for a simple surge tank

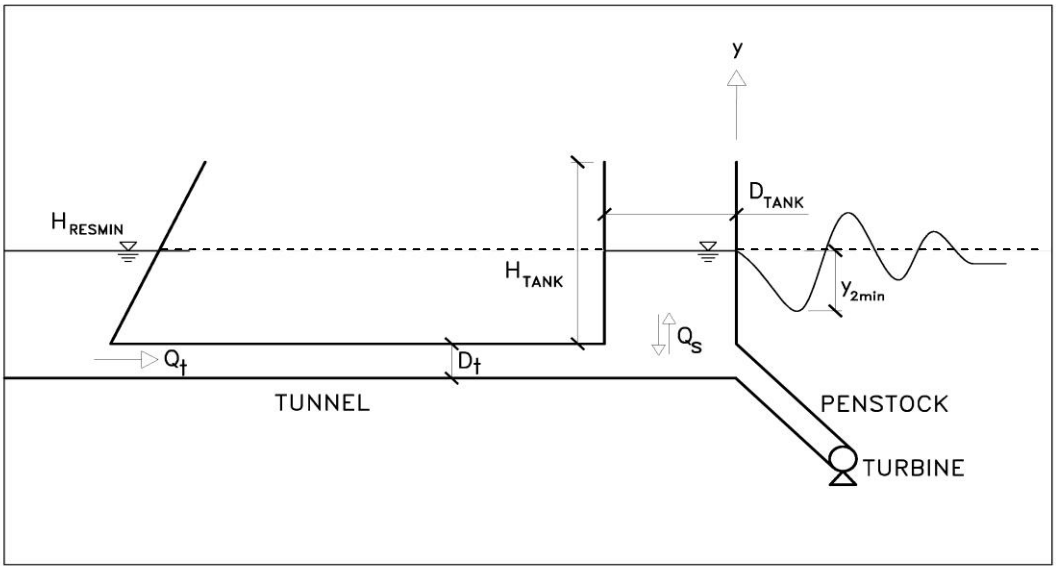

Figure 4.3 Full load acceptance with minimum discharge for a simple surge tank

4.3.2 Restricted Orifice Surge Tank

Three different models indicating the three worst case scenarios that the calculations are based on are presented in Figures (4.4) to (4.6) respectively.

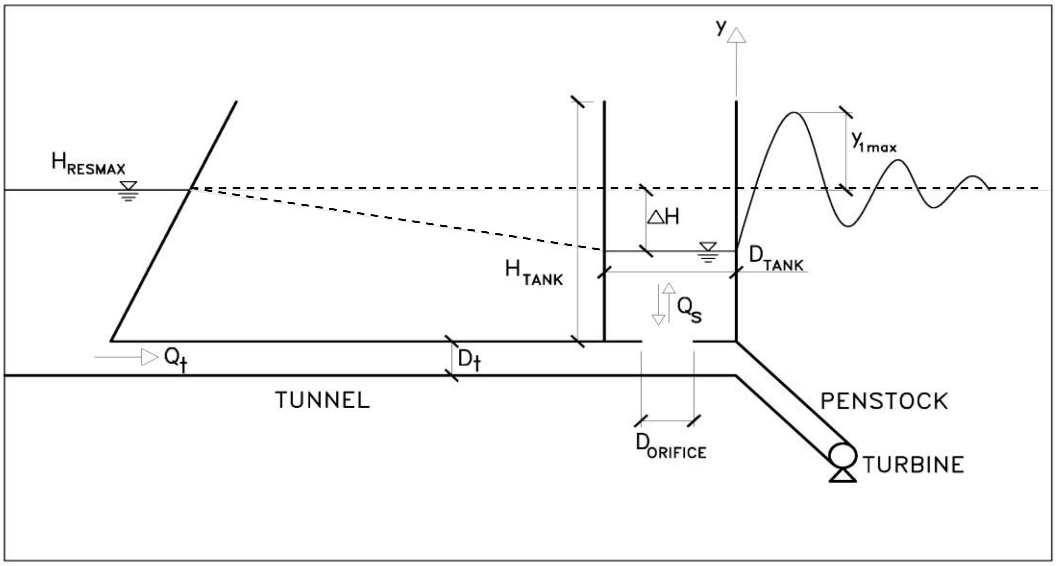

Figure 4.4 Full load rejection with maximum discharge for a restricted orifice surge tank

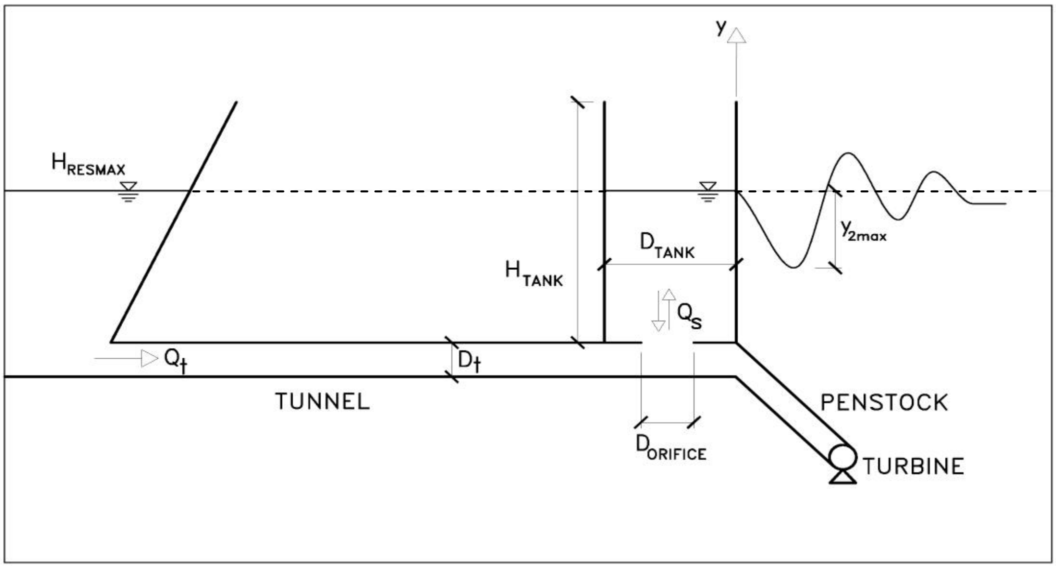

Figure 4.5 Full load acceptance with maximum discharge for a restricted orifice surge tank

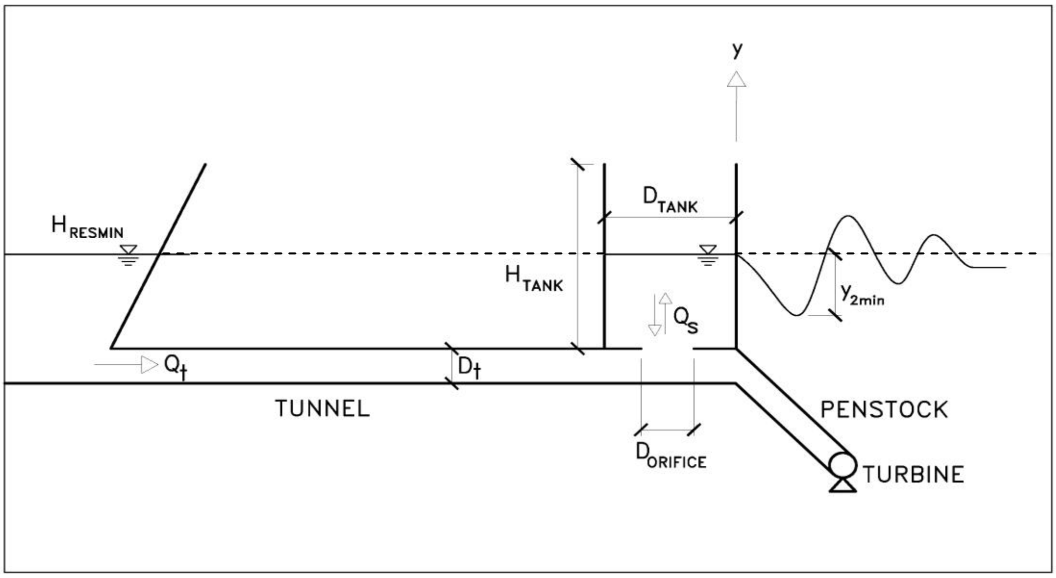

Figure 4.6 Full load acceptance with minimum discharge for a restricted orifice surge tank

4.3.3 Shafted Surge Tank

Three different models indicating three worst case scenarios that the calculations are based on are presented in Figures (4.7) to (4.9) respectively.

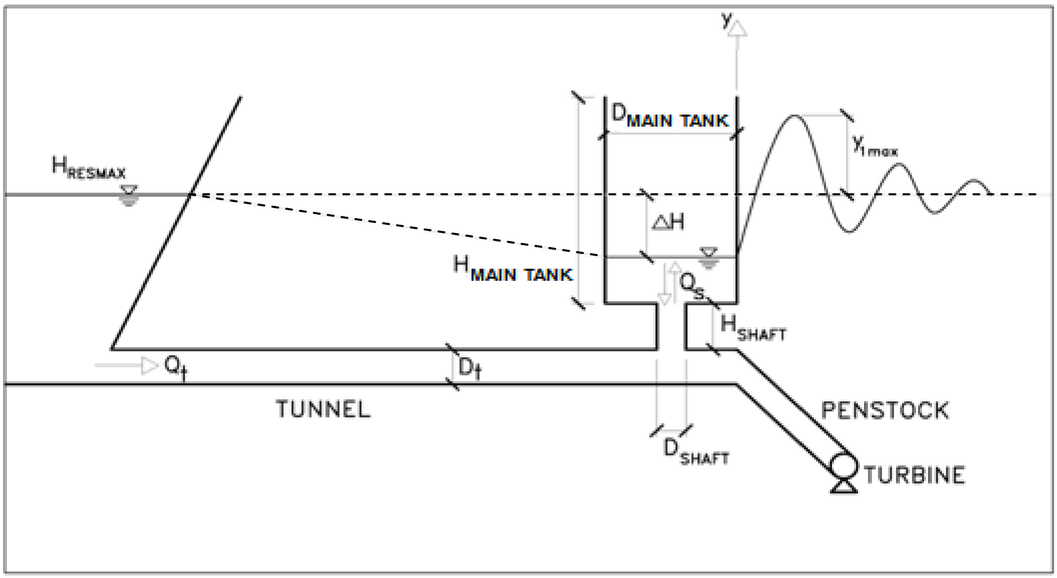

Figure 4.7 Full load rejection with maximum discharge for a shafted surge tank

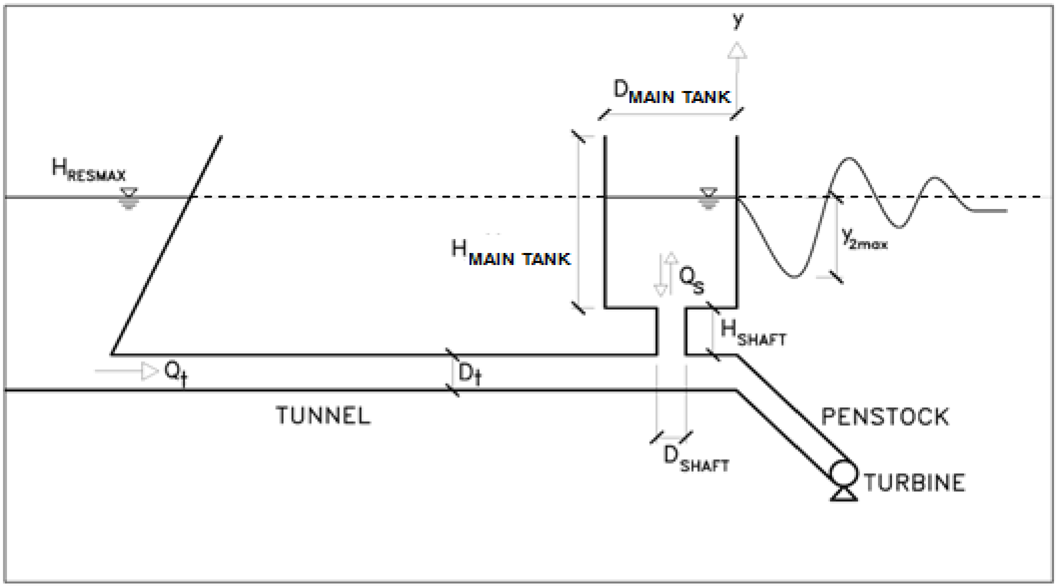

Figure 4.8 Full load acceptance with maximum discharge for a shafted surge tank

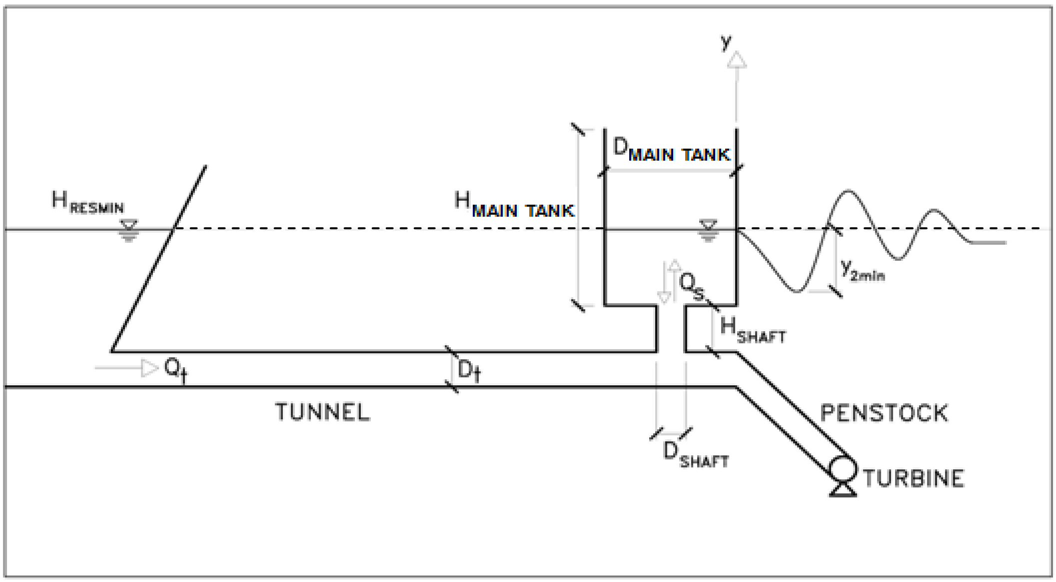

Figure 4.9 Full load acceptance with minimum discharge for a shafted surge tank

4.3.4 Governing Differential Equations

The governing differential equations of the systems, given in sections (4.3.1) to (4.3.3), are dynamic equation (4.20) and continuity equation (4.21) respectively.

$$\frac{dQ_t}{dt} = \frac{gA_t}{L} \quad -y - c_t Q_t \; Q_t \quad - c_s Q_s \; Q_s \qquad (4.20)$$

$$\frac{dy}{dt} = \frac{1}{A_s}(Q_t - \; Q_{tur}) \qquad (4.21)$$

Where, Q_t = Discharge in tunnel (m^3/s)

Q_s = Discharge in and out of surge tank (m^3/s)

Q_{tur} = Discharge through turbine (m^3/s)

g = gravitational acceleration (m/s^2)

A_t = Area of tunnel (m^2)

A_s = Area of surge tank (m^2)

L_t = Length of tunnel (m)

y = Height of water surges in the surge tank measured positive from reservoir level (m)

c_t = Coefficient of friction of tunnel (s^2/m^5)

c_s = Coefficient of friction of surge tank (s^2/m^5)

t = Time (s)

The calculation of coefficients of friction of tunnel, c_t, and surge tank, c_s, is explained in section (4.3.5)

4.3.5 Calculation of Coefficient of Head Loss, c

For the given three types of surge tanks, the head losses that need to be calculated are;

- Entrance loss in which the minor loss coefficient K, is taken as 0.5 and β_m is calculated by Equation (4.8).
- Friction loss in tunnel. β_f is calculated by Equation (4.4).
- β_m corresponding to velocity head is calculated by Equation (4.8) taking K equal to 1.
- Expansion and contraction losses, that occur when the water enters from tunnel to surge tank. β_m is calculated by Equation (4.8)
- Friction loss in surge tank. β_f is calculated by Equation (4.4)
- Friction loss in shaft for a shafted surge tank. β_f is calculated by Equation (4.4).

Then to obtain the coefficient of friction, c;

For a simple surge tank, all of the β_f and β_m values that corresponds to the entrance loss, friction loss, velocity head and the expansion loss are summed up. The total β_t, is directly converted to the coefficient c_t, by Equation (4.11).

For a restricted orifice or a shafted surge tank, all of the β_f and β_m values that corresponds to the entrance loss, friction loss, velocity head are summed up. The total β_t, is directly converted to the coefficient c_t, by Equation (4.11).

All of the β_m values that correspond to the contraction and expansion losses when the water passes from the tunnel to the surge tank through an orifice or a shaft are summed up. In addition, where available, β_f values that correspond to the friction loss in shaft for a shafted surge tank should also be summed up. Then, before the conversion, the total β_s is modified according to Equation (4.13). The reason is the varying cross-section of the tank due to the presence of orifice or shaft. After the modification is carried out, the total β_s is converted to c_s from Equation (4.12)

For all types of surge tanks, the β_f of the surge tank that corresponds to the friction in the tank is directly summed up before the conversion of β_s to c_s by Equation (4.12).

4.4 Solution of Equations of Surge Analysis

The solution of the differential Equations (4.20) and (4.21) should be performed by means of a numerical method. 3rd order Runge-Kutta is the one that is used in this thesis. An excel sheet is prepared and with the Equations (4.22) to (4.33), surge analysis is carried out.

$$F_1 = \frac{gA_t}{L}(-y_n - c_t Q_t \; Q_t \; - c_s \; Q_t - Q_{tur} \quad Q_t - Q_{tur} \tag{4.22}$$

$$F_2 = \frac{(Q_t - Q_{tur})}{A_s} \tag{4.23}$$

$$u_{11} = \Delta t \, F_1 \tag{4.24}$$

$$u_{12} = \Delta t \, F_2 \tag{4.25}$$

$$u_{21} = \Delta t \; \frac{gA_t}{L} \quad - \; y_n + \frac{u_{12}}{3} \; - c_t A \; A \; - c_s B \; B \tag{4.26}$$

$$\text{Where,} \qquad A = \; Q_t \; + \frac{u_{11}}{3} \tag{4.27}$$

$$B = \quad Q_t + \frac{u_{11}}{3} \; - Q_{tur} \tag{4.28}$$

$$u_{22} = \Delta t \; \frac{1}{A_s} \quad Q_t + \frac{u_{11}}{3} \; - Q_{tur} \tag{4.29}$$

$$u_{31} = \Delta t \; \frac{gA_t}{L} \quad - \; y_n + \frac{2u_{12}}{3} \; - c_t C \; C \; - c_s D \; D \tag{4.30}$$

$$\text{Where,} \qquad C = \; Q_t \; + \frac{2u_{11}}{3} \tag{4.31}$$

$$D = \quad Q_t + \frac{2u_{11}}{3} \; - Q_{tur} \tag{4.32}$$

$$u_{32} = \Delta t \; \frac{1}{A_s} \quad Q_t + \frac{2u_{11}}{3} \; - Q_{tur} \tag{4.33}$$

Where, A_t = Area of tunnel (m^2),

L_t = Length of tunnel (m),

y_n = If there exists a full load rejection, y_n, is taken as the water elevation in the surge tank that corresponds to the steady-state elevation. If there exists a full load acceptance, y_n, is taken as 0 (m),

c_t = Head loss coefficient for the tunnel which is used in the governing differential equation of surge analysis (s^2/m^5),

Q_t = Discharge in the tunnel (m^3/s),

Q_{tur} = Discharge passing through the turbine (m^3/s),

A_s = Area of surge tank (m^2),

Δt =Time interval (s),

g = gravitational acceleration (m/s^2).

The Equations (4.22) to (4.33) are in a general form. Therefore, coefficients are changed throughout the calculations.

For a simple surge tank, c_s should be taken as zero. However, for a restricted orifice and a shafted surge tank, c_s should be calculated as explained in section (4.3.5).

For the solution of the system, the initial conditions are introduced into the system which are tunnel and turbine discharge, tunnel length, tunnel diameter, surge tank diameter, coefficient of friction for tunnel and surge tank. Then with the given equations, surge analysis is carried out.

4.5 Determination of Tank Height

A surge tank should be designed with the conditions that it can resist the worst case scenarios throughout its operation life. Therefore, when the height is being determined, the surge analysis is carried out for three worst case scenarios.

These scenarios are;

1. Full load rejection when the system is working with full capacity and reservoir is at maximum water elevation. This would give the maximum height of the upsurge that can occur in the surge tank.
2. Full load acceptance when the system is to be put into operation with full capacity and the reservoir is at maximum water elevation.
3. Full load acceptance when the system is to be put into operation with minimum capacity and the reservoir is at minimum water elevation.

Last two scenarios would give the minimum water elevation that could occur in the tank.

4.5.1 Procedure

The procedure that is given below is same for a simple and restricted orifice surge tank. However, there are some differences in the second part of the calculation of the height of a shafted surge tank. The reason is the different structural formation of this kind of surge tank.

The procedure followed is given step by step.

For the determination of upper elevation of the tank;

- First, height of the maximum upsurge that can occur in the system is obtained.
- Then this value is directly added to water elevation in the surge tank corresponding to steady-state.
- Last, maximum upper elevation of the surge tank is obtained by the summation of freeboard and the predetermined water elevation in the tank.

For the determination of the tank height;

- A surge analysis is carried out for two cases. First, full load acceptance when the system is in operation with minimum tunnel discharge and minimum water elevation in reservoir. Second, full load acceptance when the system is in operation with maximum tunnel discharge and maximum water elevation in reservoir.
- Then these values are directly subtracted from the water elevation that was present in the surge tank initially.
- From the obtained water elevations, the value smaller than the other gives the minimum water elevation present in the surge tank.
- After that, height of the water column in the surge tank is calculated.
- With the obtained height of the water column, the system is checked for any vortex formation following the procedure explained in Section (4.2.2.2).
- If there is no vortex formation for the obtained bottom elevation; the height is determined by subtracting the bottom elevation of the tank from the upper elevation of tank for a simple and a restricted orifice surge tank. However, for a shafted surge tank;
- If there is no vortex formation for the calculated bottom elevation, first the height of the main tank is determined.
- For this purpose, a safety value that is calculated by Equation (4.18) is subtracted from the water elevation in the main tank. Therefore, the bottom elevation of the main tank is obtained. Then, subtracting the bottom elevation from the upper elevation of the surge tank, height of the main tank is obtained.
- Consequently, height of the shaft is determined by subtracting the bottom elevation of the shaft from the bottom elevation of the main tank.

CHAPTER 5

DIMENSIONAL ANALYSIS

In order to determine the effective dimensions for different types of surge tanks, a dimensional analysis is conducted. The formation of the non-dimensional parameters and the developed empirical equations are explained in detail in this chapter.

5.1 Purpose of Analysis

The purpose of this kind of analysis is to develop empirical equations that directly calculates the surge tank height for a given tank diameter, if available orifice or shaft diameter. This way the surge tank is dimensioned in a way that it always satisfies the system conditions.

5.2 Dimensional Analysis

5.2.1 Dimensional Analysis for a Simple Surge Tank

First the system parameters are grouped.

The system parameters that are known initially are;

- The maximum water level in the reservoir, H_{resmax}
- The minimum water level in the reservoir, H_{resmin}
- The maximum discharge in the tunnel, Q_{max}
- The minimum discharge in the tunnel, Q_{min}
- The tunnel diameter, D_t
- The tunnel length, L_t
- The coefficient of friction of tunnel, c_t
- The kinematic viscosity of water, ν

The system parameters that are not known initially are;

- The height of the maximum upsurge corresponding to the case when the system is working with full capacity and the reservoir is at maximum water elevation, y_{1max}.
- The height of the maximum downsurge corresponding to the case when the system is to be put into operation with full capacity and the reservoir is at maximum water elevation, y_{2max}.
- The height of the maximum downsurge corresponding to the case when the system is to be put into operation with min capacity and the reservoir is at minimum water elevation, y_{2min}.

The surge tank parameters that are not known and are going to be determined are;

- The diameter of the surge tank, D_t
- The height of the surge tank, H_t

In light of these system parameters, the following eleven π parameters are formed according to the Buckingham's π theorem.

$$H_{tank} = f\ D_{tank}, Q_{min}, Q_{max}, L_t, D_t, c_t, y_{1max}, y_{2max}, y_{2min}, H_{resmax}, H_{resmin}, \rho, \mu$$

$$\pi_1 = \frac{H_{tank}}{D_{tank}}, \pi_2 = \frac{Q_{min}}{Q_{max}}, \pi_3 = \frac{L_t}{D_{tank}}, \pi_4 = \frac{D_t}{D_{tank}}, \pi_5 = \frac{c_t * Q_{max}^2}{D_{tank}}$$

$$\pi_6 = \frac{y_{1max}}{D_{tank}}, \pi_7 = \frac{y_{2max}}{D_{tank}}, \pi_8 = \frac{y_{2min}}{D_{tank}}, \pi_9 = \frac{H_{resmax}}{D_{tank}}, \pi_{10} = \frac{H_{resmin}}{D_{tank}}, \pi_{11} = \frac{\nu * D_{tank}}{Q_{max}}$$

For the development of empirical equations, first all of the non-dimensional parameters were tried. However, it is observed that using all of the non-dimensional parameters gives nonsense outcomes. As a result, with reduction of some parameters by trial and error, and using the data corresponding to seven different dams* given in (Appendix A.1), three different empirical equations for surge tank height and three different empirical equations for y_{1max}, y_{2max}, y_{2min} are developed.

Equations developed for surge heights;

The first equation;

$$\frac{y_{1max}}{D_{tank}} = c_0 \left(\frac{Q_{min}}{Q_{max}}\right)^{c_1} \left(\frac{D_t}{D_{tank}}\right)^{c_2} \left(\frac{c_t Q_{max}^2}{D_{tank}}\right)^{c_3} \left(\frac{L_t}{D_{tank}}\right)^{c_4} \left(\frac{\nu D_{tank}}{Q_{max}}\right)^{c_5} \quad (5.1)$$

Table 5.1: The coefficients of the equation (5.1)

c_0	1.792
c_1	-0.023
c_2	1.964
c_3	0.175
c_4	0.348
c_5	0.009

*Ermenek, Çine, Gezende, Atasu (corresponding data obtained from State Hydraulic Works), remaining three dams were obtained from Examples one to three (Cofcof, 2011)

The second equation;

$$\frac{y_{2max}}{D_{tank}} = c_0 {\frac{Q_{min}}{Q_{max}}}^{c_1} {\frac{D_t}{D_{tank}}}^{c_2} {\frac{c_t Q_{max}^2}{D_{tank}}}^{c_3} {\frac{L_t}{D_{tank}}}^{c_4} {\frac{\nu D_{tank}}{Q_{max}}}^{c_5} \qquad 5.2$$

Table 5.2: The coefficients of the equation (5.2)

c_0	1.548
c_1	-0.054
c_2	1.231
c_3	0.437
c_4	0.210
c_5	-0.027

The third equation;

$$\frac{y_{2min}}{D_{tank}} = c_0 {\frac{Q_{min}}{Q_{max}}}^{c_1} {\frac{D_t}{D_{tank}}}^{c_2} {\frac{c_t Q_{max}^2}{D_{tank}}}^{c_3} {\frac{L_t}{D_{tank}}}^{c_4} {\frac{\nu D_{tank}}{Q_{max}}}^{c_5} \qquad (5.3)$$

Table 5.3: The coefficients of the equation (5.3)

c_0	1.530
c_1	0.993
c_2	1.328
c_3	0.394
c_4	0.247
c_5	-0.021

Equations developed for surge tank height;

The first equation;

$$\frac{H_{tank}}{D_{tank}} = c_0 \left(\frac{Q_{min}}{Q_{max}}\right)^{c1} \left(\frac{c_t Q_{max}^2}{D_{tank}}\right)^{c2} \left(\frac{y_{1max}}{D_{tank}}\right)^{c3} \left(\frac{\nu D_{tank}}{Q_{max}}\right)^{c4} \quad 5.4$$

Table 5.4: The coefficients of the equation (5.4)

c_0	$5.30*10^2$
c_1	-0.681
c_2	-0.255
c_3	0.727
c_4	0.355

The second equation;

$$\frac{H_{tank}}{D_{tank}} = c_0 \left(\frac{Q_{min}}{Q_{max}}\right)^{c1} \left(\frac{c_t Q_{max}^2}{D_{tank}}\right)^{c2} \left(\frac{y_{2min}}{D_{tank}}\right)^{c3} \left(\frac{\nu D_{tank}}{Q_{max}}\right)^{c4} \quad 5.5$$

Table 5.5: The coefficients of the equation (5.5)

c_0	$5.33*10^2$
c_1	-1.780
c_2	-0.574
c_3	1.089
c_4	0.393

The third equation ;

$$\frac{H_{tank}}{D_{tank}} = c_0 \left(\frac{Q_{min}}{Q_{max}}\right)^{c1} \left(\frac{c_t Q_{max}^2}{D_{tank}}\right)^{c2} \left(\frac{y_{2max}}{D_{tank}}\right)^{c3} \left(\frac{\nu D_{tank}}{Q_{max}}\right)^{c4} \qquad 5.6$$

Table 5.6: The coefficients of the equation (5.6)

c_0	$6.39*10^2$
c_1	-0.638
c_2	-0.645
c_3	1.185
c_4	0.408

A flowchart for the application of the method developed for a simple surge tank is given in Figure (5.1).

ASSUME D_{tank}

↓

USE Equation (4.4) and CALCULATE β_f that corresponds to tunnel friction

↓

USE Equation (4.8) and CALCULATE β_m corresponds to entrance loss, velocity head and expansion loss

↓

SUM UP β_f and β_m , OBTAIN β_t

↓

USE Equation (4.11) and CONVERT β_t to c_t

↓

USE Equation (4.4) and CALCULATE β_f that corresponds to surge tank friction

↓

β_f is equal to β_s

↓

USE Equation (4.12) and CONVERT β_s to c_s

↓

OBTAIN SURGE HEIGHT
CHOOSE one of the empirical equations (5.1) to (5.3)

↓

OBTAIN TANK HEIGHT
USE empirical equation (5.4), if the empirical equation (5.1) is chosen
USE empirical equation (5.5), if the empirical equation (5.3) is chosen
USE empirical equation (5.6), if the empirical equation (5.2) is chosen

Figure 5.1 Flowchart for the application of the method developed for a simple surge tank

5.2.2 Dimensional Analysis for a Restricted Orifice Surge Tank

First the system parameters that are known initially are grouped.

The system parameters that are known initially are;

- The maximum water level in the reservoir, H_{resmax}
- The minimum water level in the reservoir, H_{resmin}
- The maximum discharge in the tunnel, Q_{max}
- The minimum discharge in the tunnel, Q_{min}
- The tunnel diameter, D_t
- The tunnel length, L_t
- The coefficient of friction of tunnel, c_t
- The kinematic viscosity of water, ν

The system parameters that are not known initially are;

- The height of the maximum upsurge corresponding to the case when the system is working with full capcacity and the water level in the reservoir is maximum, y_{1max}.
- The height of the maximum downsurge corresponding to the case when the system is to be put into operation with full capacity and the reservoir is at maximum water elevation, y_{2max}.
- The height of the maximum downsurge corresponding to the case when the system is to be put into operation with minimum capacity and the reservoir is at minimum water elevation mum, y_{2min}.
- The coefficient of orifice, c_{orf}.

The surge tank parameters that are not known and are going to be determined are;

- The diameter of the surge tank, D_t
- The diameter of the orifice, D_{orf}
- The height of the surge tank, H_t

In light of these system parameters, the following thirteen π parameters are formed according to the Buckingham's π theorem.

$$H_{tank} = f\left(\begin{matrix} D_{tank}, D_{orf,}, Q_{min}, Q_{max}, L_t, D_t, c_{t,} c_{orf}, \\ y_{1max}, y_{2max}, y_{2min}, H_{resmax}, H_{resmin}, \rho, \mu \end{matrix}\right)$$

$$\pi_1 = \frac{H_{tank}}{D_{tank}}, \pi_2 = \frac{D_{orf}}{D_{tank}}, \pi_3 = \frac{Q_{min}}{Q_{max}}, \quad \pi_4 = \frac{L_t}{D_{tank}}, \pi_5 = \frac{D_t}{D_{tank}}$$

$$\pi_6 = \frac{c_t * Q_{max}^2}{D_{tank}}, \pi_7 = \frac{c_{orf} * Q_{max}^2}{D_{tank}}, \pi_8 = \frac{y_{1max}}{D_{tank}}, \pi_9 = \frac{y_{2max}}{D_{tank}}$$

$$\pi_{10} = \frac{y_{2min}}{D_{tank}}, \pi_{11} = \frac{H_{resmax}}{D_{tank}}, \pi_{12} = \frac{H_{resmin}}{D_{tank}}, \pi_{13} = \frac{\nu * D_{tank}}{Q_{max}}$$

As explained for a simple surge tank, similarly for a restricted orifice surge tank, some of the non-dimensional parameters are reduced by trial and error for the formation of empirical equations. As a result, with the data corresponding to seven different dams* given in (Appendix A.2), Equation (5.7) is developed for the calculation of surge tank height.

$$\frac{H_{tank}}{D_{tank}} = c_0 \left(\frac{D_{orf}}{D_{tank}}\right)^{c1} \left(\frac{Q_{min}}{Q_{max}}\right)^{c2} \left(\frac{(c_t + c_{orf})Q_{max}^2}{D_{tank}}\right)^{c3} \left(\frac{y_{2min}}{D_{tank}}\right)^{c4} \left(\frac{\nu D_{tank}}{Q_{max}}\right)^{c5} \qquad 5.7$$

Table 5.7: The coefficients of the equation (5.7)

c_0	1.641
c_1	0.005
c_2	-0.655
c_3	0.518
c_4	-0.052
c_5	0.029

*Ermenek, Çine, Gezende, Atasu (corresponding data obtained from State Hydraulic Works), remaining three dams were obtained from Examples one to three (Cofcof, 2011)

A flowchart for the application of the method developed for a restricted orifice surge tank is given in Figure (5.2)

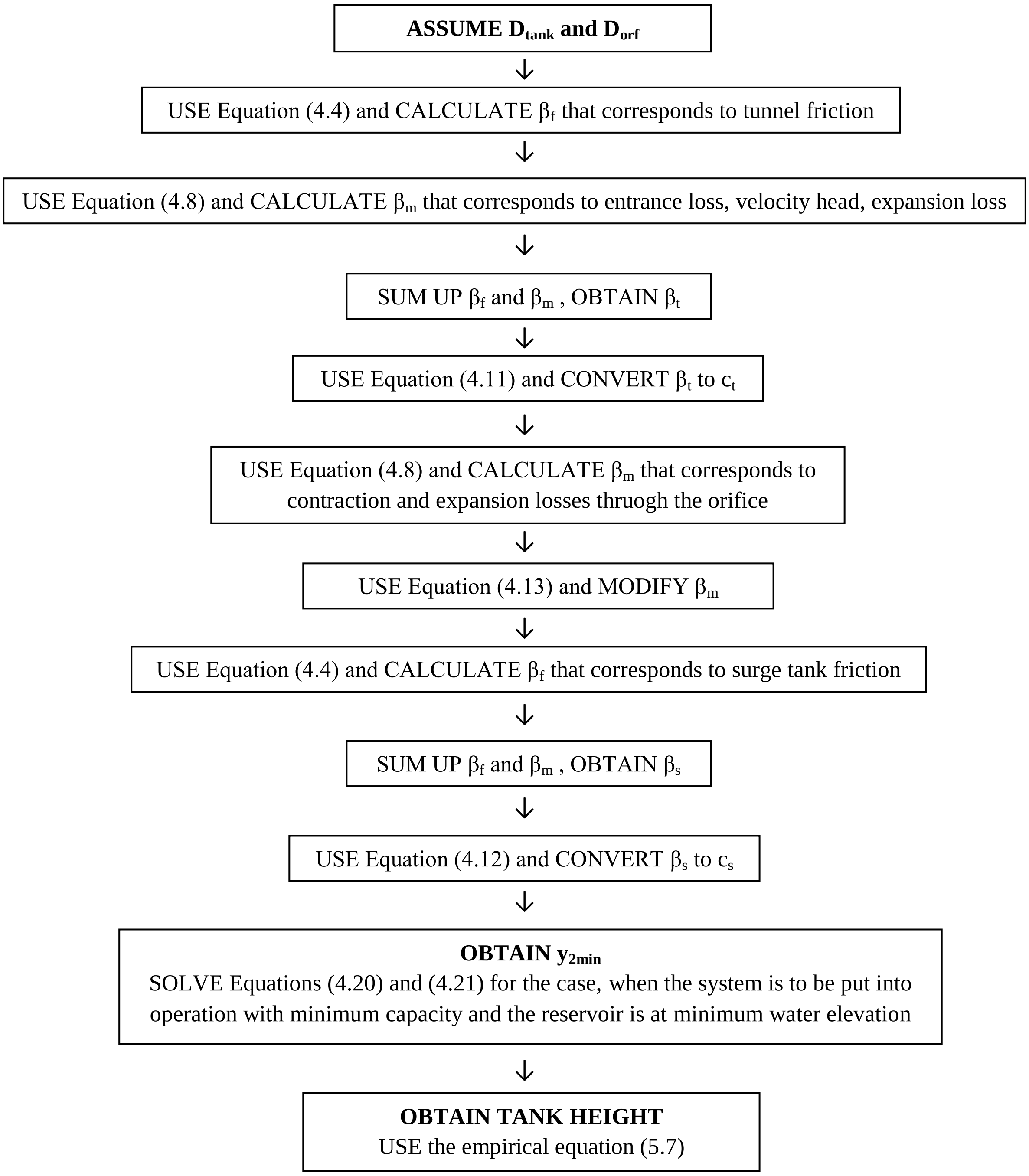

Figure 5.2 Flowchart for the application of the method developed for a restricted orifice tank

5.2.3 Dimensional Analysis for a Shafted Surge Tank

First the system parameters that are known initially are grouped.

The system parameters that are known initially are;

- The maximum water level in the reservoir, H_{resmax}
- The minimum water level in the reservoir, H_{resmin}
- The maximum discharge in the tunnel, Q_{max}
- The minimum discharge in the tunnel, Q_{min}
- The tunnel diameter, D_t
- The tunnel length, L_t
- The coefficient of friction of tunnel, c_t
- The kinematic viscosity of water, ν

The system parameters that are not known initially are;

- The height of the maximum upsurge corresponding to the case when the system is working with full capacity and the water level in the reservoir is maximum, y_{1max}.
- The height of the maximum downsurge corresponding to the case when the system is to be put into operation with full capacity and the reservoir is at maximum water elevation, y_{2max}.
- The height of the maximum downsurge corresponding to the case when the system is to be put into operation with minimum capacity and the reservoir is at minimum water elevation, y_{2min}.
- The coefficient of friction of shaft, c_{shaft}.

The surge tank parameters that are not known and are going to be determined are;

- The diameter of the surge tank, D_t
- The diameter of shaft, D_{shaft}
- The height of shaft, H_{shaft}
- The height of the surge tank, H_t

In light of these system parameters, the following fourteen π parameters are formed according to the Buckingham's π theorem.

$$H_{tank} = f \begin{array}{c} D_{tank}, D_{sHaft}, H_{main\ tank}, Q_{min}, Q_{max}, L_t, D_t, c_t, c_{sHaft,} \\ y_{1max}, y_{2max}, y_{2min}, H_{resmax}, H_{resmin}, \rho, \mu, \end{array}$$

$$\pi_1 = \frac{H_{tank}}{D_{tank}}, \pi_2 = \frac{D_{shaft}}{D_{tank}}, \pi_3 = \frac{H_{main\ tank}}{D_{tank}}, \pi_4 = \frac{Q_{min}}{Q_{max}}, \quad \pi_5 = \frac{L_t}{D_{tank}}, \pi_6 = \frac{D_t}{D_{tank}}$$

$$\pi_7 = \frac{c_t * Q_{max}^2}{D_{tank}}, \pi_8 = \frac{c_{shaft} * Q_{max}^2}{D_{tank}}, \pi_9 = \frac{y_{1max}}{D_{tank}}, \pi_{10} = \frac{y_{2max}}{D_{tank}}$$

$$\pi_{11} = \frac{y_{2min}}{D_{tank}}, \pi_{11} = \frac{H_{resmax}}{D_{tank}}, \pi_{13} = \frac{H_{resmin}}{D_{tank}}, \pi_{14} = \frac{\nu * D_{tank}}{Q_{max}}$$

As explained for a simple surge tank, similarly for a shafted surge tank, some of the non-dimensional parameters are reduced by trial and error for the formation of empirical equations. As a result, with the data corresponding to five different dams* given in (Appendix A.3), two different empirical equations for the calculation of tank height and one empirical equation for the calculation of the main tank height are developed.

Equation developed for the calculation of main tank height;

$$\frac{H_{main\ tank}}{D_{tank}} = c_0 \left(\frac{D_{shaft}}{D_{tank}}\right)^{c_1} \left(\frac{L_t}{D_{tank}}\right)^{c_2} \left(\frac{c_{shaft} Q_{max}^2}{D_{tank}}\right)^{c_3} \left(\frac{\nu D_{tank}}{Q_{max}}\right)^{c_5} \quad (5.8)$$

Table 5.8: The coefficients of the equation (5.8)

c_0	2.490
c_1	1.217
c_2	0.354
c_3	0.165
c_4	-0.027

*Ermenek, Gezende (corresponding data obtained from State Hydraulic Works), remaining three dams were obtained from Examples one to three (Cofcof, 2011)

Equations developed for the calculation of the tank heights;

The first equation;

$$\frac{H_{tank}}{D_{tank}} = c_0 \; {\frac{D_{shaft}}{D_{tank}}}^{c_1} \; {\frac{Q_{min}}{Q_{max}}}^{c_2} \; {\frac{c_{shaft}Q_{max}^2}{D_{tank}}}^{c_3} \; {\frac{y_{1max}}{D_{tank}}}^{c_4} \; {\frac{\nu D_{tank}}{Q_{max}}}^{c_5} \; {\frac{H_{main\ tank}}{D_{tank}}}^{c_6} \quad (5.9)$$

Table 5.9: The coefficients of the equation (5.9)

c_0	$1.592*10^3$
c_1	1.281
c_2	-0.675
c_3	0.214
c_4	-0.142
c_5	0.303
c_6	0.308

The second equation;

$$\frac{H_{tank}}{D_{tank}} = c_0 \; {\frac{D_{shaft}}{D_{tank}}}^{c_1} \; {\frac{D_t}{D_{tank}}}^{c_2} \; {\frac{c_{shaft}Q_{max}^2}{D_{tank}}}^{c_3} \; {\frac{y_{1max}}{D_{tank}}}^{c_4} \; {\frac{\nu D_{tank}}{Q_{max}}}^{c_5} \; {\frac{H_{main\ tank}}{D_{tank}}}^{c_6} \quad (5.10)$$

Table 5.10: The coefficients of the equation (5.10)

c_0	0.049
c_1	0.396
c_2	-0.681
c_3	0.101
c_4	-0.087
c_5	-0.214
c_6	0.935

A flowchart for the application of the method developed for a shafted surge tank is given in Figure(5.3).

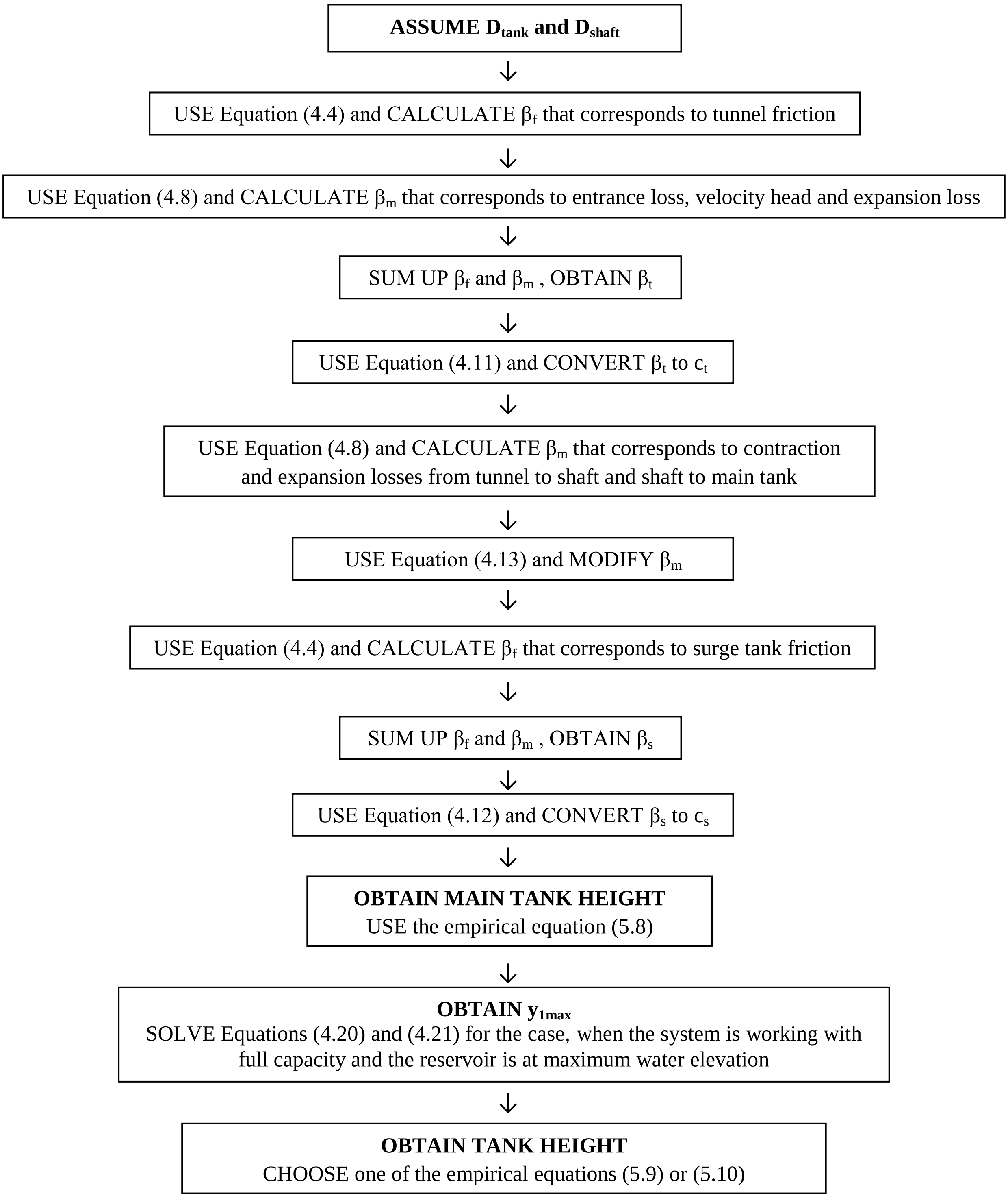

Figure 5.3 Flowchart for the application of the method developed for a shafted surge tank

CHAPTER 6

CASE STUDIES

In this chapter, with the equations developed in chapter five, case studies are done. A regression analysis is conducted to determine the correlation between the parameters. The differences between the obtained results are discussed.

6.1 Simple Surge Tank

For a simple surge tank, Equations (5.1) to (5.6) are developed. Equations (5.1) to (5.3) are developed for obtaining y_{1max}, y_{2max}, y_{2min}. Equations (5.4) to (5.6) are developed for obtaining surge tank heights. Seven different case studies are done. One of them is given in this section. For the sake of completeness, the rest is given in Appendix A.1.

Initial conditions of Çine Dam are given in Table (6.1);

Table 6.1: The initial conditions of Çine Dam

H_{resmax} (m)	264.8
H_{resmin} (m)	205
Q_{min} (m^3/s)	9.75
Q_{max} (m^3/s)	35
L_t (m)	2926
D_t (m)	3.9

For the surge heights, the actual values calculated and the results obtained with the developed equations are given in Table (6.2).

For the tank heights, the actual values calculated and the results obtained with the developed equations are given in Table (6.3).

Table 6.2: The actual values calculated and the results obtained with the developed Equations for surge heights

D_{tank} (m)	c_t	y_{1max} (m)	y_{1max} obtained from Equation (5.1)	y_{2max} (m)	y_{2max} obtained from Equation (5.2)	y_{2min} (m)	y_{2min} obtained from Equation (5.3)
10	0.004949253	15.92	16.76	20.38	20.69	5.54	5.67
11	0.004965490	14.14	14.57	18.59	19.01	5.04	5.17
12	0.004978173	12.66	12.82	17.11	17.59	4.63	4.75
13	0.004988243	11.41	11.39	15.85	16.37	4.28	4.39
14	0.004996357	10.35	10.21	14.77	15.32	3.97	4.08
15	0.005002983	9.43	9.22	13.84	14.40	3.71	3.81
16	0.005008459	8.63	8.39	13.03	13.59	3.48	3.58
17	0.005013033	7.93	7.67	12.32	12.87	3.28	3.37
18	0.005016892	7.31	7.05	11.68	12.23	3.10	3.19
19	0.005020176	6.76	6.51	11.11	11.65	2.94	3.02
20	0.005022993	6.27	6.03	10.61	11.12	2.80	2.87
21	0.005025427	5.82	5.61	10.15	10.64	2.67	2.74
22	0.005027543	5.43	5.24	9.73	10.21	2.55	2.61
23	0.005029395	5.06	4.91	9.35	9.81	2.44	2.50
24	0.005031025	4.74	4.61	9.01	9.44	2.34	2.40
25	0.005032466	4.44	4.34	8.69	9.10	2.25	2.30
26	0.005033747	4.16	4.10	8.40	8.78	2.16	2.22
27	0.005034890	3.91	3.87	8.14	8.49	2.09	2.14
28	0.005035915	3.68	3.67	7.89	8.21	2.01	2.06
29	0.005036836	3.47	3.49	7.66	7.96	1.95	1.99
30	0.005037669	3.27	3.31	7.45	7.72	1.88	1.92

Table 6.3: The actual values calculated and the results obtained with the developed Equations for tank heights

D_{tank} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_t	H_{tank} (m)	H_{tank} obtained from developed equations		
						Equation(5.4)	Equation(5.5)	Equation(5.6)
10	15.92	20.38	5.54	0.004949253	93	96	98	99
11	14.14	18.59	5.04	0.004965490	90	95	96	96
12	12.66	17.11	4.63	0.004978173	89	95	94	94
13	11.41	15.85	4.28	0.004988243	87	94	93	92
14	10.35	14.77	3.97	0.004996357	86	94	91	90
15	9.43	13.84	3.71	0.005002983	85	93	90	88
16	8.63	13.03	3.48	0.005008459	84	92	89	87
17	7.93	12.32	3.28	0.005013033	83	92	88	85
18	7.31	11.68	3.10	0.005016892	82	91	87	84
19	6.76	11.11	2.94	0.005020176	82	90	86	83
20	6.27	10.61	2.80	0.005022993	81	89	85	82
21	5.82	10.15	2.67	0.005025427	80	88	84	81
22	5.43	9.73	2.55	0.005027543	80	87	83	81
23	5.06	9.35	2.44	0.005029395	80	86	83	80
24	4.74	9.01	2.34	0.005031025	79	85	82	79
25	4.44	8.69	2.25	0.005032466	79	84	81	79
26	4.16	8.40	2.16	0.005033747	78	83	81	78
27	3.91	8.14	2.09	0.005034890	78	82	80	78
28	3.68	7.89	2.01	0.005035915	78	81	80	78
29	3.47	7.66	1.95	0.005036836	78	80	79	77
30	3.27	7.45	1.88	0.005037669	77	79	79	77

6.2 Restricted Orifice Surge Tank

For obtaining the tank height of a restricted orifice surge tank, Equation (5.7) is developed. Seven different case studies are done. One of them is given in this section. For the sake of completeness, the rest is given in Appendix A.2.

Initial conditions of the dam in Example one are given in Table (6.4) (Cofcof, 2011) ;

Table 6.4: The initial conditions of the dam in Example one

H_{resmax} (m)	450
H_{resmin} (m)	425
Q_{min} (m^3/s)	150
Q_{max} (m^3/s)	250
L_t (m)	700
D_t (m)	8.5

For the tank heights, the actual values calculated and the results obtained with the developed equations are given in Table (6.5).

Table 6.5: The actual values calculated and the results obtained with the developed Equation for surge tank heights

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obtained from Equation.(5.7)
9	2	4.58	6.89	5.51	0.006715604	53	47
10	2	3.51	5.83	4.64	0.006808181	52	45
10	3	12.74	14.8	10.81	0.001219779	63	62
11	2	2.71	5.03	3.98	0.006877263	51	43
11	3	10.72	12.8	9.41	0.001249046	61	60
12	2	2.09	4.42	3.46	0.006930139	50	41
13	2	1.62	3.95	3.05	0.006971488	50	40
13	3	7.84	9.94	7.37	0.001289396	57	57
13	4	14.28	16.18	11.01	0.000370079	65	66
14	2	1.24	3.58	2.71	0.007004421	49	39
14	3	6.79	8.90	6.62	0.001303621	56	56
14	4	12.72	14.63	10.01	0.000377756	63	65
15	3	5.91	8.04	5.98	0.001315176	55	54
15	4	11.40	13.31	9.15	0.000384029	61	64
15	5	15.29	17.12	11.03	0.000140769	66	68
16	2	0.73	3.06	2.21	0.007052933	49	37
16	3	5.17	7.31	5.44	0.001324687	54	53
16	4	10.27	12.19	8.42	0.000389216	60	63
16	5	13.98	15.81	10.23	0.000143955	65	67
16	6	16.08	17.91	11.14	0.000060520	67	69
16	7	17.16	18.99	11.56	0.000027152	68	69

Table 6.5.continued: The actual values calculated and the results obtained with the developed Equation for surge tank heights

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obtained from Equation.(5.7)
17	2	0.56	2.90	2.01	0.007071089	48	36
17	3	4.55	6.69	4.98	0.001332606	53	52
17	4	9.30	11.22	7.78	0.000393552	59	62
17	5	12.84	14.67	9.53	0.000146632	63	66
17	6	14.89	16.71	10.42	0.000062296	66	68
17	7	15.96	17.79	10.85	0.000028384	67	69
17	8	16.50	18.34	11.06	0.000013195	68	69
18	2	0.44	2.78	1.85	0.007086330	48	35
18	3	4.01	6.16	4.58	0.001339267	53	51
18	4	8.45	10.38	7.22	0.000397210	58	61
18	5	11.84	13.67	8.91	0.000148901	62	65
18	6	13.84	15.66	9.79	0.000063809	64	67
18	7	14.90	16.72	10.22	0.000029443	66	68
18	8	15.44	17.27	10.43	0.000013958	66	69
19	2	0.36	2.71	1.7	0.007099245	48	35
19	3	3.54	5.70	4.23	0.001344922	52	50
19	4	7.71	9.65	6.73	0.000400324	57	60
19	5	10.95	12.78	8.36	0.000150839	61	65
19	6	12.91	14.72	9.23	0.000065109	63	67
19	7	13.96	15.78	9.65	0.000030357	64	68
19	8	14.50	16.33	9.87	0.000014621	65	68

Table 6.5.continued: The actual values calculated and the results obtained with the developed Equation for surge tank heights

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obtained from Equation.(5.7)
20	2	0.30	2.66	1.58	0.007110286	48	34
20	3	3.14	5.30	3.93	0.001349764	52	49
20	4	7.05	9.00	6.29	0.000402996	56	59
20	5	10.16	12.00	7.87	0.000152506	60	64
20	6	12.07	13.88	8.72	0.000066231	62	66
20	7	13.11	14.91	9.15	0.000031150	63	67
20	8	13.65	15.48	9.36	0.000015201	64	68
21	2	0.26	2.63	1.48	0.007119797	48	34
21	3	2.79	4.95	3.66	0.001352940	51	49
21	4	6.47	8.42	5.90	0.000405305	56	58
21	5	9.46	11.29	7.43	0.000153951	59	63
21	6	11.32	13.13	8.26	0.000067206	61	66
21	7	12.34	14.16	8.69	0.000031842	63	67
21	8	12.89	14.71	8.9	0.00001571	63	67
22	2	0.23	2.61	1.39	0.007128047	48	33
22	3	2.48	4.65	3.42	0.001357567	51	48
22	4	5.95	7.91	5.55	0.000407314	55	58
22	5	8.82	10.66	7.03	0.000155211	58	63
22	6	10.64	12.44	7.85	0.000068059	61	65
22	7	11.65	13.46	8.27	0.000032449	62	66
22	8	12.19	14.01	8.48	0.000016158	62	67

Table 6.5.continued: The actual values calculated and the results obtained with the developed Equation for surge tank heights

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obtained from Equation.(5.7)
23	2	0.21	2.59	1.31	0.007135251	48	33
23	3	2.20	4.38	3.20	0.001360736	50	47
23	4	5.48	7.45	5.23	0.000409072	54	57
23	5	8.24	10.08	6.66	0.000156315	58	62
23	6	10.02	11.82	7.47	0.000068808	60	65
23	7	11.02	12.83	7.89	0.000032985	61	66
23	8	11.56	13.38	8.11	0.000016554	62	67
24	2	0.19	2.57	1.24	0.007141577	48	32
24	3	1.96	4.14	3.01	0.001363522	50	46
24	4	5.06	7.03	4.94	0.000410619	54	56
24	5	7.72	9.56	6.33	0.000157288	57	62
24	6	9.46	11.26	7.13	0.000069470	59	64
24	7	10.44	12.25	7.54	0.000033459	60	65
24	8	10.98	12.79	7.76	0.000016906	61	66
25	2	0.18	2.56	1.18	0.007147163	48	32
25	3	1.75	3.92	2.84	0.001365984	50	46
25	4	4.69	6.66	4.68	0.000411987	53	56
25	5	7.25	9.09	6.03	0.000158151	56	61
25	6	8.94	10.74	6.81	0.000070057	58	64
25	7	9.91	11.72	7.22	0.000033880	60	65
25	8	10.45	12.26	7.44	0.00001722	60	66

Table 6.5.continued: The actual values calculated and the results obtained with the developed Equation for surge tank heights

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obtained from Equation.(5.7)
26	2	0.16	2.55	1.13	0.007152119	48	32
26	3	1.56	3.74	2.68	0.001368170	50	45
26	4	4.34	6.32	4.45	0.000413203	53	55
26	5	6.81	8.65	5.75	0.000158918	56	61
26	6	8.47	10.26	6.52	0.000070581	58	63
26	7	9.43	11.23	6.93	0.000034257	59	65
26	8	9.96	11.77	7.14	0.000017501	60	65
27	2	0.15	2.54	1.09	0.007156537	48	32
27	3	1.39	3.57	2.54	0.001370119	49	45
27	4	4.03	6.01	4.23	0.000414288	53	55
27	5	6.41	8.26	5.50	0.000159603	55	60
27	6	8.03	9.83	6.25	0.000071049	57	63
27	7	8.98	10.77	6.66	0.000034594	59	64
27	8	9.50	11.31	6.87	0.000017754	59	65
28	2	0.14	2.54	1.05	0.007160492	48	32
28	3	1.24	3.42	2.41	0.001371865	49	44
28	4	3.74	5.73	4.03	0.000415261	52	54
28	5	6.05	7.89	5.26	0.000160218	55	60
28	6	7.63	9.42	6.00	0.000071470	57	62
28	7	8.56	10.35	6.40	0.000034897	58	64
28	8	9.08	10.89	6.62	0.000017981	59	65

Table 6.5.continued: The actual values calculated and the results obtained with the developed Equation for surge tank heights

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obtained from Equation.(5.7)
29	2	0.13	2.53	1.02	0.007164046	48	32
29	3	1.10	3.29	2.30	0.001373435	49	44
29	4	3.48	5.47	3.84	0.000416136	52	53
29	5	5.71	7.55	5.04	0.000160772	55	59
29	6	7.25	9.05	5.77	0.000071849	56	62
29	7	8.17	9.97	6.17	0.000035171	58	64
29	8	8.69	10.49	6.38	0.000018187	58	64

6.3 Shafted Surge Tank

For a simple surge tank, Equations (5.8) to (5.10) are developed. Equation (5.8) is developed for obtaining main tank heights. Equations (5.9) and (5.10) are developed for obtaining surge tank heights. Seven different case studies are done. One of them is given in this section. For the sake of completeness, the rest is given in Appendix A.3.

Initial conditions of Ermenek Dam are given in Table (6.6);

Table 6.6: The initial conditions of Ermenek Dam

H_{resmax} (m)	694
H_{resmin} (m)	660
Q_{min} (m^3/s)	26
Q_{max} (m^3/s)	104
L_t (m)	8064
D_t (m)	5.6

For the main tank heights, the actual values calculated and the results obtained with the developed equation are given in Table (6.7).

For the tank heights, the actual values calculated and the results obtained with the developed equations are given in Table (6.8).

Table 6.7: The actual values calculated and the results obtained with the developed Equation for main tank height

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obtained from Equation.(5.8)
9	2	35.11	49.73	16.16	0.007810068	102	89
10	2	28.94	43.59	14.31	0.007902645	87	83
10	3	48.35	62.34	16.52	0.001294129	133	100
11	2	24.09	38.76	12.82	0.007971727	78	77
11	3	42.30	56.22	14.97	0.001323377	118	94
11	4	47.39	61.48	15.38	0.000340473	131	106
11	5	48.81	62.99	15.48	0.000103917	134	114
12	2	20.20	34.89	11.58	0.008024603	72	72
12	3	37.31	51.16	13.68	0.001345956	106	88
12	4	42.29	56.32	14.09	0.000352447	118	100
12	5	43.71	57.83	14.19	0.000110984	122	108
13	2	17.05	31.74	10.54	0.008065952	67	68
13	3	33.14	46.93	12.59	0.001363727	96	83
13	4	38.01	51.96	13.00	0.000361966	108	94
13	5	39.42	53.47	13.11	0.000116682	111	103
14	2	14.47	29.16	9.65	0.008098885	63	64
14	3	29.60	43.33	11.65	0.001377952	88	78
14	4	34.35	48.24	12.06	0.000369643	99	90
14	5	35.75	49.75	12.17	0.000121328	103	98

Table 6.7.continued: The actual values calculated and the results obtained with the developed Equation for main tank heights

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obtained from Equation (5.8)
15	2	12.34	27.03	8.89	0.008125534	59	61
15	3	26.58	40.24	10.85	0.001389507	80	74
15	4	31.20	45.03	11.26	0.000375916	91	85
15	5	32.59	46.53	11.36	0.000125156	95	93
16	2	10.57	25.28	8.23	0.008147397	57	58
16	3	23.97	37.57	10.14	0.001399018	75	71
16	4	28.47	42.23	10.55	0.000381103	85	81
16	5	29.83	43.71	10.66	0.000128343	88	89
17	2	9.10	23.83	7.66	0.008165553	54	55
17	3	21.69	35.24	9.52	0.001406937	71	68
17	4	26.07	39.76	9.92	0.000385438	79	78
17	5	27.42	41.24	10.03	0.000131020	82	85
18	2	7.88	22.65	7.15	0.008180793	52	53
18	3	19.70	33.19	8.96	0.001413598	68	65
18	4	23.96	37.59	9.37	0.000389097	74	75
18	5	25.28	39.04	9.48	0.000133288	77	82
19	2	6.86	21.71	6.69	0.008193709	50	51
19	3	17.95	31.38	8.47	0.001419253	66	62
19	4	22.08	35.65	8.87	0.000392211	71	72
19	5	23.38	37.08	8.98	0.000135226	73	79

Table 6.7.continued: The actual values calculated and the results obtained with the developed Equation for main tank height

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obtained from Equation (5.8)
20	2	6.02	20.98	6.29	0.008204750	49	49
20	3	16.40	29.77	8.03	0.001424095	63	60
20	4	20.41	33.91	8.43	0.000394883	69	69
20	5	21.68	35.32	8.54	0.000136894	70	76
21	2	5.32	20.43	5.93	0.008214260	47	47
21	3	15.02	28.34	7.62	0.001428271	61	58
21	4	18.91	32.35	8.02	0.000397192	66	66
21	5	20.16	33.74	8.13	0.000138339	68	73
22	2	4.73	20.05	5.60	0.008222511	46	46
22	3	13.79	27.06	7.26	0.001431898	59	56
22	4	17.56	30.93	7.66	0.000399200	64	64
22	5	18.78	32.30	7.76	0.000139598	66	71
23	2	4.24	19.80	5.30	0.008229715	45	44
23	3	12.69	25.92	6.93	0.001435067	58	54
23	4	16.34	29.65	7.32	0.000400958	62	62
23	5	17.53	31.00	7.43	0.000140702	64	69
24	2	3.84	19.63	5.03	0.008236041	45	43
24	3	11.70	24.89	6.62	0.001437853	56	52
24	4	15.23	28.49	7.01	0.000402505	61	60
24	5	16.40	29.81	7.12	0.000141676	62	66

Table 6.7.continued: The actual values calculated and the results obtained with the developed Equation for main tank height

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obtained from Equation (5.8)
25	2	3.49	19.53	4.79	0.008241627	44	41
25	3	10.81	23.97	6.34	0.001440315	55	51
25	4	14.22	27.42	6.73	0.000403874	59	58
25	5	15.36	28.72	6.84	0.000142538	61	64
26	2	3.20	19.47	4.56	0.008246583	43	40
26	3	10.01	23.14	6.09	0.001442501	53	49
26	4	13.31	26.45	6.47	0.000405090	58	57
26	5	14.42	27.72	6.58	0.000143305	59	63
27	2	2.94	19.42	4.35	0.008251001	43	39
27	3	9.29	22.41	5.85	0.001444450	52	48
27	4	12.47	25.56	6.23	0.000406175	56	55
27	5	13.55	26.80	6.34	0.000143991	58	61
28	2	2.72	19.40	4.16	0.008254955	42	38
28	3	8.63	21.75	5.63	0.001446196	51	47
28	4	11.70	24.74	6.01	0.000407148	55	54
28	5	12.75	25.95	6.11	0.000144606	57	59
29	2	2.53	19.38	3.99	0.008258509	42	37
29	3	8.04	21.17	5.42	0.001447766	50	45
29	4	10.99	23.99	5.80	0.000408023	54	52
29	5	12.02	25.17	5.91	0.000145160	56	58

Table 6.8: The actual values calculated and the results obtained with the developed Equations for tank heights

							H_{tank} obtained from developed equations	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
9	2	35.11	49.73	16.16	0.007810068	120	108	117
10	2	28.94	43.59	14.31	0.007902645	113	102	105
10	3	48.35	62.34	16.52	0.001294129	136	124	145
11	2	24.09	38.76	12.82	0.007971727	107	98	97
11	3	42.30	56.22	14.97	0.001323377	129	118	134
11	4	47.39	61.48	15.38	0.000340473	135	129	142
11	5	48.81	62.99	15.48	0.000103917	137	134	141
12	2	20.20	34.89	11.58	0.008024603	102	95	93
12	3	37.31	51.16	13.68	0.001345956	123	113	124
12	4	42.29	56.32	14.09	0.000352447	129	125	132
12	5	43.71	57.83	14.19	0.000110984	131	130	132
13	2	17.05	31.74	10.54	0.008065952	99	93	89
13	3	33.14	46.93	12.59	0.001363727	118	109	115
13	4	38.01	51.96	13.00	0.000361966	124	120	124
13	5	39.42	53.47	13.11	0.000116682	125	126	124
14	2	14.47	29.16	9.65	0.008098885	95	91	86
14	3	29.60	43.33	11.65	0.001377952	114	105	108
14	4	34.35	48.24	12.06	0.000369643	119	116	117
14	5	35.75	49.75	12.17	0.000121328	121	122	118

Table 6.8.continued: The actual values calculated and the results obtained with the developed Equations for tank heights

							H_{tank} obtained from developed equations	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
15	2	12.34	27.03	8.89	0.008125534	93	89	83
15	3	26.58	40.24	10.85	0.001389507	110	101	101
15	4	31.20	45.03	11.26	0.000375916	116	113	111
15	5	32.59	46.53	11.36	0.000125156	117	119	111
16	2	10.57	25.28	8.23	0.008147397	91	88	81
16	3	23.97	37.57	10.14	0.001399018	107	98	96
16	4	28.47	42.23	10.55	0.000381103	112	109	105
16	5	29.83	43.71	10.66	0.000128343	114	116	106
17	2	9.10	23.83	7.66	0.008165553	89	87	79
17	3	21.69	35.24	9.52	0.001406937	104	96	94
17	4	26.07	39.76	9.92	0.000385438	109	106	100
17	5	27.42	41.24	10.03	0.000131020	111	113	101
18	2	7.88	22.65	7.15	0.008180793	88	86	78
18	3	19.70	33.19	8.96	0.001413598	102	94	91
18	4	23.96	37.59	9.37	0.000389097	107	103	95
18	5	25.28	39.04	9.48	0.000133288	108	110	97
19	2	6.86	21.71	6.69	0.008193709	86	85	77
19	3	17.95	31.38	8.47	0.001419253	100	93	89
19	4	22.08	35.65	8.87	0.000392211	105	101	93
19	5	23.38	37.08	8.98	0.000135226	106	107	93

Table 6.8.continued: The actual values calculated and the results obtained with the developed Equations for tank heights

							H_{tank} obtained from developed equations	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
20	2	6.02	20.98	6.29	0.008204750	85	84	76
20	3	16.40	29.77	8.03	0.001424095	98	91	88
20	4	20.41	33.91	8.43	0.000394883	103	100	91
20	5	21.68	35.32	8.54	0.000136894	104	106	91
21	2	5.32	20.43	5.93	0.008214260	84	83	76
21	3	15.02	28.34	7.62	0.001428271	96	90	86
21	4	18.91	32.35	8.02	0.000397192	101	98	90
21	5	20.16	33.74	8.13	0.000138339	102	104	89
22	2	4.73	20.05	5.60	0.008222511	84	83	75
22	3	13.79	27.06	7.26	0.001431898	95	89	85
22	4	17.56	30.93	7.66	0.000399200	99	97	88
22	5	18.78	32.30	7.76	0.000139598	101	103	88
23	2	4.24	19.80	5.30	0.008229715	83	82	75
23	3	12.69	25.92	6.93	0.001435067	93	88	83
23	4	16.34	29.65	7.32	0.000400958	98	95	87
23	5	17.53	31.00	7.43	0.000140702	99	101	87
24	2	3.84	19.63	5.03	0.008236041	83	82	75
24	3	11.70	24.89	6.62	0.001437853	92	87	82
24	4	15.23	28.49	7.01	0.000402505	96	94	85
24	5	16.40	29.81	7.12	0.000141676	98	100	85

Table 6.8.continued: The actual values calculated and the results obtained with the developed Equations for tank heights

							H_{tank} obtained from developed equations	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
25	2	3.49	19.53	4.79	0.008241627	82	81	74
25	3	10.81	23.97	6.34	0.001440315	91	86	81
25	4	14.22	27.42	6.73	0.000403874	95	93	84
25	5	15.36	28.72	6.84	0.000142538	97	99	84
26	2	3.20	19.47	4.56	0.008246583	82	81	74
26	3	10.01	23.14	6.09	0.001442501	90	85	81
26	4	13.31	26.45	6.47	0.000405090	94	92	83
26	5	14.42	27.72	6.58	0.000143305	95	98	83
27	2	2.94	19.42	4.35	0.008251001	82	80	74
27	3	9.29	22.41	5.85	0.001444450	89	84	80
27	4	12.47	25.56	6.23	0.000406175	93	91	83
27	5	13.55	26.80	6.34	0.000143991	94	97	82
28	2	2.72	19.40	4.16	0.008254955	81	80	74
28	3	8.63	21.75	5.63	0.001446196	88	83	79
28	4	11.70	24.74	6.01	0.000407148	92	90	82
28	5	12.75	25.95	6.11	0.000144606	93	96	82
29	2	2.53	19.38	3.99	0.008258509	81	80	74
29	3	8.04	21.17	5.42	0.001447766	88	83	79
29	4	10.99	23.99	5.80	0.000408023	91	89	81
29	5	12.02	25.17	5.91	0.000145160	92	95	81

6.4 Discussion of Results

The actual and the calculated values corresponding to surge tank heights for the dams, Ermenek, Gezende, Atasu, Çine and three dams in Examples from one to three (Cofcof, 2011) are presented in Figure (D.1) of Appendix D.

With the data obtained from the case studies, a regression analysis is conducted.

The coefficients of determination obtained are given in Table (6.9).

Table 6.9: The coefficients of determination obtained from the regression analyses

Simple Surge Tank	
Equation	**r^2**
(5.1)	0.99
(5.2)	0.99
(5.3)	0.99
(5.4)	0.98
(5.5)	0.98
(5.6)	0.98
Restricted Orifice Surge Tank	
Equation	**r^2**
(5.7)	0.89
Shafted Surge Tank	
Equation	**r^2**
(5.8)	0.90
(5.9)	0.91
(5.10)	0.90

From Table (6.9) it can clearly be seen that, r^2, varies between 0,9 and 1. This means the correlation between the data ,from which the Equations (5.1) to (5.10) are developed, and the system parameters are well obtained.

When a comparison is done between the coefficients of determination of the equations corresponding to three different surge tanks, r^2 of simple surge tank is higher than the restricted orifice and the shafted surge tank. In a simple surge tank only the tank diameter is assigned and the corresponding tank height is calculated. However, in a restricted orifice surge tank, the diameter of tank and orifice should be assigned in order to calculate the corresponding tank height. Similarly, in a shafted surge tank, the diameter of the main tank and the shaft are assigned to calculate the corresponding heights. Therefore more than one parameter play role in the calculations. This is the reason why r^2 obtained for these kinds of tanks are less compared to a simple surge tank.

In addition, the coefficient of determination for none of the surge tanks is equal to one. This result in some underestimations and overestimations for the values obtained from the developed empirical equations. The designer may think, will the obtained dimensions still satisfy the limiting conditions. However, throughout the calculations the surge tank is designed within safety limits for a problem of vortex and overflow. Therefore, as the differences for obtained values are not significantly great in magnitude, the dimensions of the designed surge tank will still satisfy the limiting conditions.

As a concluding remark, the coefficients of determination can not be increased anymore for higher correlation. The reason is, all of the empirical equations are obtained with reduction or addition of the non-dimensional parameters by trial and error. Therefore, all of the combinations possible were tried and the empirical equations are developed with the given highest coefficients of determination.

CHAPTER 7

FINANCIAL CONSIDERATIONS

The first consideration while designing a surge tank is the functionality and safety of the tank. However, in engineering, designing a structure not only means creating a structure which functions well, but also creating a structure which is feasible from economical point of view. In this chapter, some alternative ways of comparison is suggested to the designer so that he or she is able to dimension a surge tank, which functions well and costs less.

7.1 Cost of a Surge Tank

Before the introduction of the alternative comparison ways, a cost function is defined. The parameters of the function are determined regardless of topography.

The cost of a surge tank depends on;

- The amount of excavation, (m^3),
- The amount of concrete, (m^3),
- The amount of formwork, (m^2),
- The amount of reinforcement, (tons),

Or depends on;

- The amount of excavation, (m^3),
- The amount of steel, (tons),

If the tank is a steel tube.

The tanks are considered as reinforced-concrete surge tanks.

The cost formulae for each type of tank are;

For simple and restricted-orifice surge tank;

$$
\begin{aligned}
\mathrm{COST} = {} & \frac{\pi}{4} D_{tank}^{2} \;\; H_{tank} \;\; C_{ex} \\
& + \;\; \pi D_{tank} \; + \; \pi \;\; D_{tank} + a \quad H_{tank} \;\; C_{fwork} \\
& + \;\; \frac{\pi}{4} \;\; D_{tank} + a \;\; ^{2} - D_{tank}^{2} \quad H_{tank} \;\; C_{co} \\
& \qquad + \;\; \text{amount of reinforcement} \;\; C_{re} \qquad (7.1)
\end{aligned}
$$

For a shafted surge tank;

$$
\begin{aligned}
\mathrm{COST} = {} & \frac{\pi}{4} D_{main\ tank}^{2} \;\; H_{main\ tank} + \frac{\pi}{4} D_{shaft}^{2} \;\; H_{shaft} \;\; C_{ex} \\
& + \;\; \begin{matrix} \pi D_{main\ tank} \; + \; \pi \;\; D_{main\ tank} + a \quad H_{main\ tank} \\ + \;\; \pi D_{shaft} \; + \; \pi \;\; D_{shaft} + a \quad H_{shaft} \end{matrix} \;\; C_{fwork} \\
& + \;\; \begin{matrix} \frac{\pi}{4} \;\; D_{main\ tank} + a \;\; ^{2} - D_{main\ tank}^{2} \quad H_{main\ tank} \\ + \;\; \frac{\pi}{4} \;\; D_{shaft} + a \;\; ^{2} - D_{shaft}^{2} \quad H_{shaft} \end{matrix} \;\; C_{co} \\
& + \;\; \text{amount of reinforcement} \;\; C_{re} \qquad 7.2
\end{aligned}
$$

Where, D_{tank} = Diameter of surge tank (m)

H_{tank} = Height of surge tank (m)

a = Thickness of concrete lining (m)

$D_{main\ tank}$ = Diameter of main tank of a shafted surge tank (m)

D_{shaft} = Diameter of shaft of a surge tank (m)

$H_{main\ tank}$ = Height of main tank of a shafted surge tank (m)

H_{shaft} = Height of shaft of a shafted surge tank (m)

C_{ex} = Unit cost of excavation (TL)

C_{fwork} = Unit cost of formwork (TL)

C_{co} = Unit cost of concrete (TL)

C_{re} = Unit cost of reinforcement (TL)

The unit costs are taken as (COFCOF,2011);

- C_{ex} = 9.5 TL/m^3
- C_{fwork} = 26 TL/m^2
- C_{co} = 126.7 TL/m^3
- C_{re} = 1350 TL/ton

7.2 Behaviour of Cost Function with respect to System Parameters

In order to obtain a surge tank that costs less, first the behavior of the cost function should be investigated. In light of this concept graphs showing the relation between the diameter of a surge tank, cost, tank height and height of maximum upsurge and downsurge are drawn.

7.2.1 Behaviour of Cost Function for a Simple Surge Tank

All of the values that Figures (7.1) and (7.2) are based on, are given in (Appendix B.1) including the initial system conditions for which the calculations are carried out accordingly.

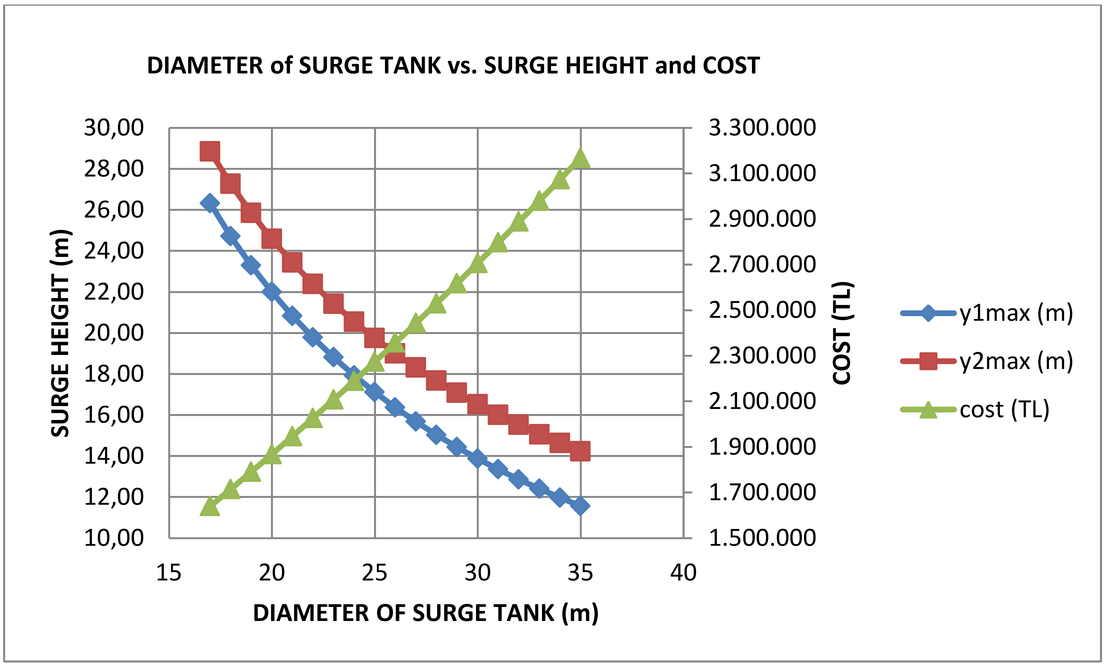

Figure 7.1 The graph of Tank diameter vs. Surge height and Cost for a simple surge tank

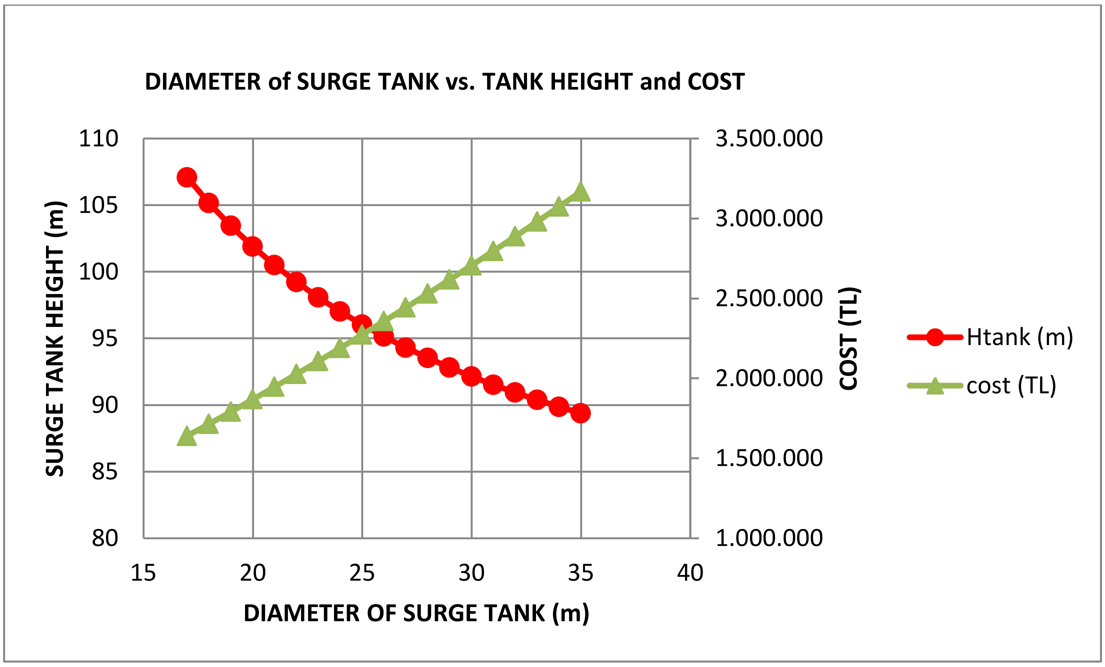

Figure 7.2 The graph of Tank diameter vs. Tank height and Cost for a simple surge tank

When Figures (7.1) and (7.2) are observed, it can clearly be seen that when the diameter of the surge tank is increased, the height of maximum upsurge, y1max, and the height of maximum downsurge, y_{2max}, are decreased resulting in a decrease in tank height. However, this decrease in the tank height can not compensate the increase in cost. As a result if the diameter of a simple surge tank is increased, the surge tank functions better whereas the cost is increased.

7.2.2 Behaviour of Cost Function for a Restricted-Orifice Surge Tank

All of the values that Figures (7.3) to (7.6) are based on, are given in (Appendix B.2) including the initial system conditions for which the calculations are carried out accordingly.

Height and cost of a restricted orifice surge tank is dependent on, both the tank diameter and the orifice diameter. Therefore, the graphs are drawn first, for a constant orifice diameter and variable tank diameters in order to see the effect of the tank diameter. Second, they are drawn for a constant tank diameter and variable orifice diameters in order to see the effect of the orifice diameter.

For a constant orifice diameter of 4 m and variable tank diameters;

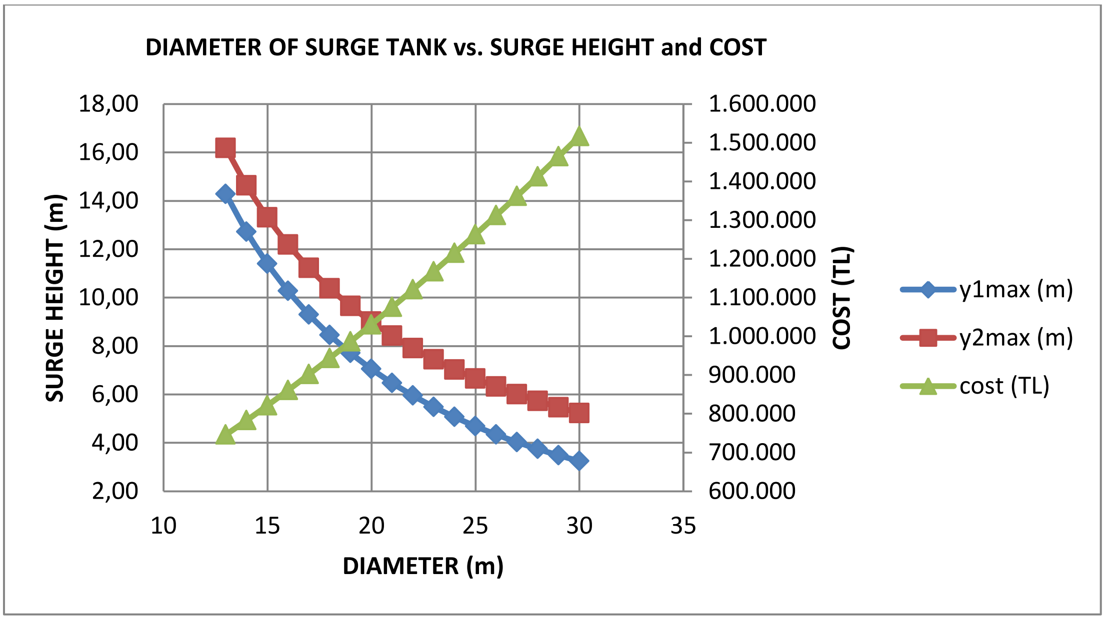

Figure 7.3 The graph of Tank diameter vs. Surge height and Cost, for a constant orifice diameter of 4 m, for a restricted orifice surge tank

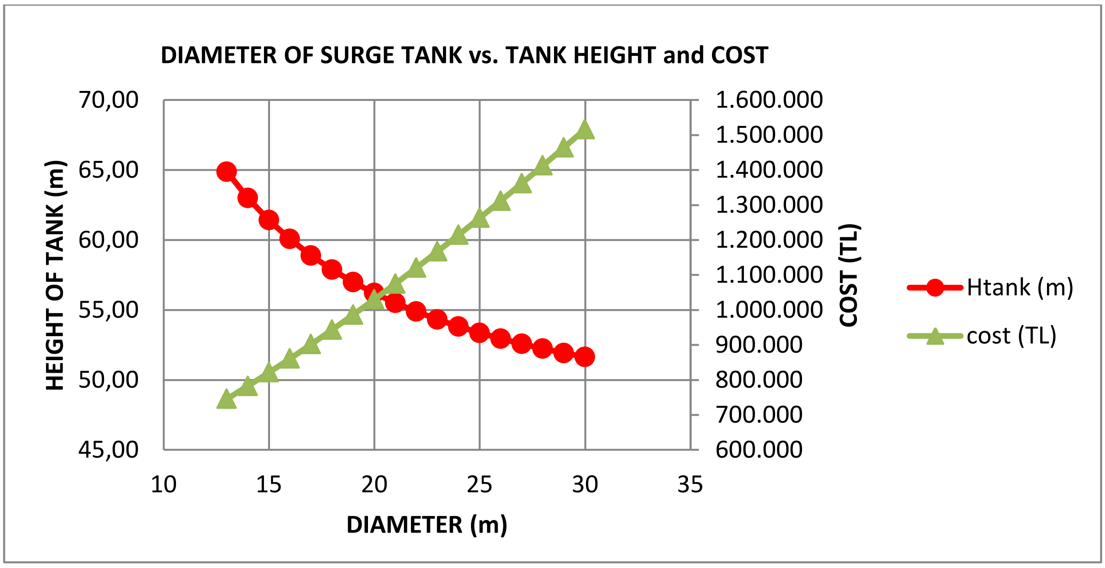

Figure 7.4 The graph of Tank diameter vs. Tank height and Cost, for a constant orifice diameter of 4 m, for a restricted orifice surge tank

From Figures (7.3) and (7.4), it is observed that when the tank diameter is increased the height of the maximum upsurge, y_{1max}, and the height of the maximum downsurge, y_{2max}, is decreased resulting in a decrease in tank height. However, again this decrease in tank height can not compensate the increase in cost.

For a constant tank diameter of 23 m and variable orifice diameter;

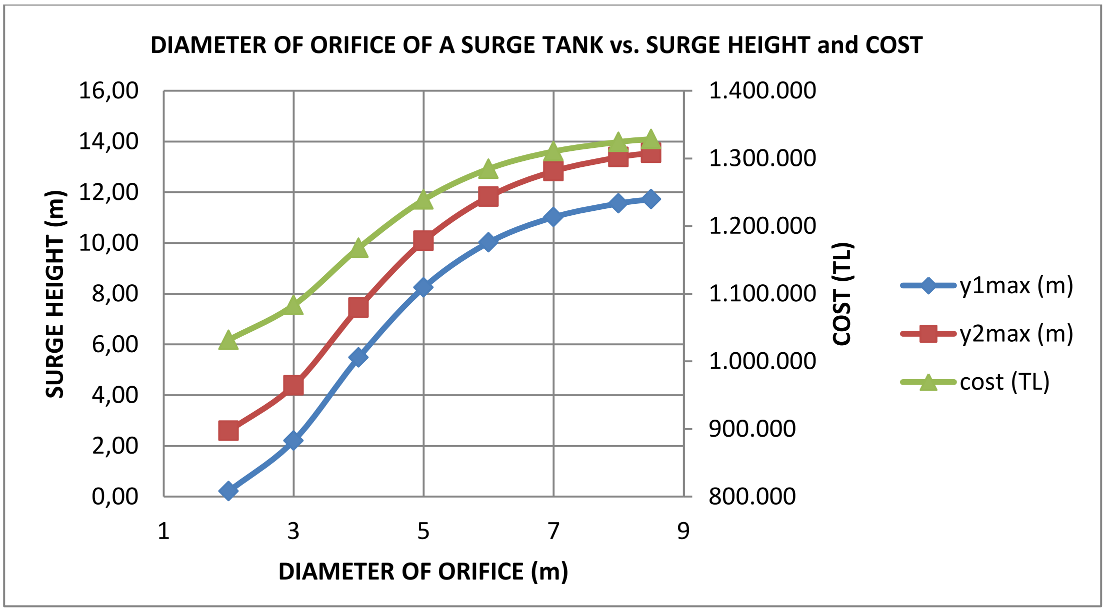

Figure 7.5 The graph of Orifice diameter vs. Surge height and Cost, for a constant tank diameter of 23 m, for a restricted orifice surge tank

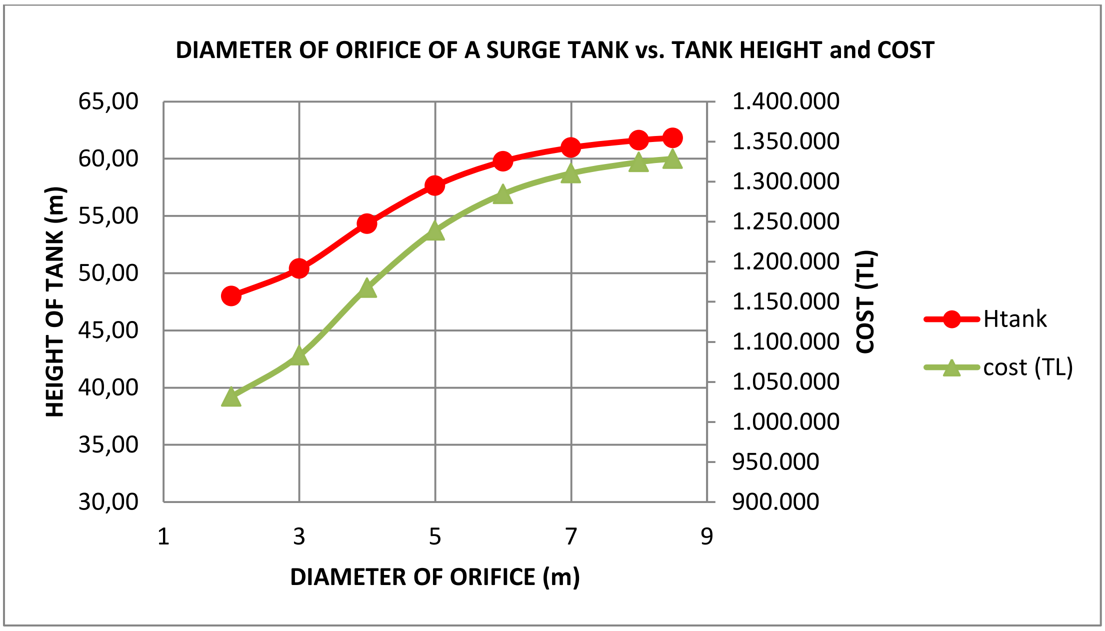

Figure 7.6 The graph of Orifice diameter vs. Tank height and Cost, for a constant tank diameter of 23 m, for a restricted orifice surge tank

From Figures (7.5) and (7.6), it can be seen that, increasing orifice diameter, increases the height of the maximum upsurge, y_{1max}, and the height of the maximum downsurge, y_{2max}, resulting in an increase in tank height. Therefore, the cost is also increased.

7.2.3 Behaviour of Cost Function for a Shafted Surge Tank

All of the values that Figures (7.7) to (7.10) are based on, are given in (Appendix B.3) including the initial system conditions for which the calculations are carried out accordingly.

Height and cost of a shafted surge tank is dependent on, both the tank diameter and the shaft diameter. Therefore, the graphs are drawn first, for a constant shaft diameter and variable tank diameters in order to see the effect of the tank diameter. Second, they are drawn for a constant tank diameter and variable shaft diameters in order to see the effect of the shaft diameter.

For a constant shaft diameter of 6 m and variable tank main tank diameter;

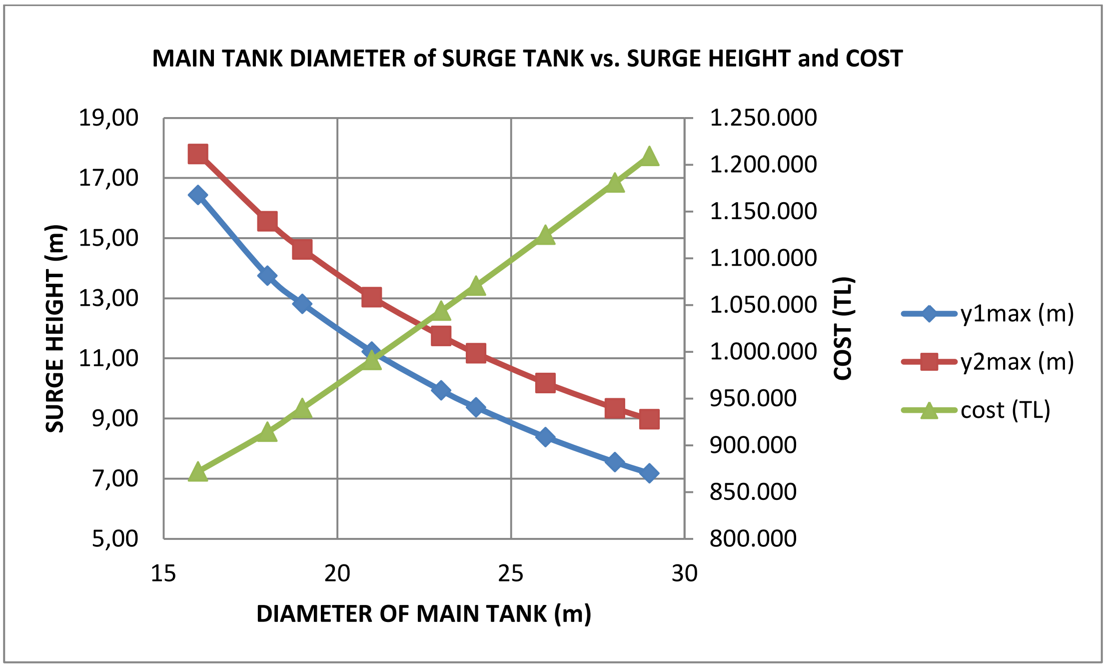

Figure 7.7 The graph of Main Tank diameter vs. Surge height and Cost, for a constant shaft diameter of 6 m, for a shafted surge tank

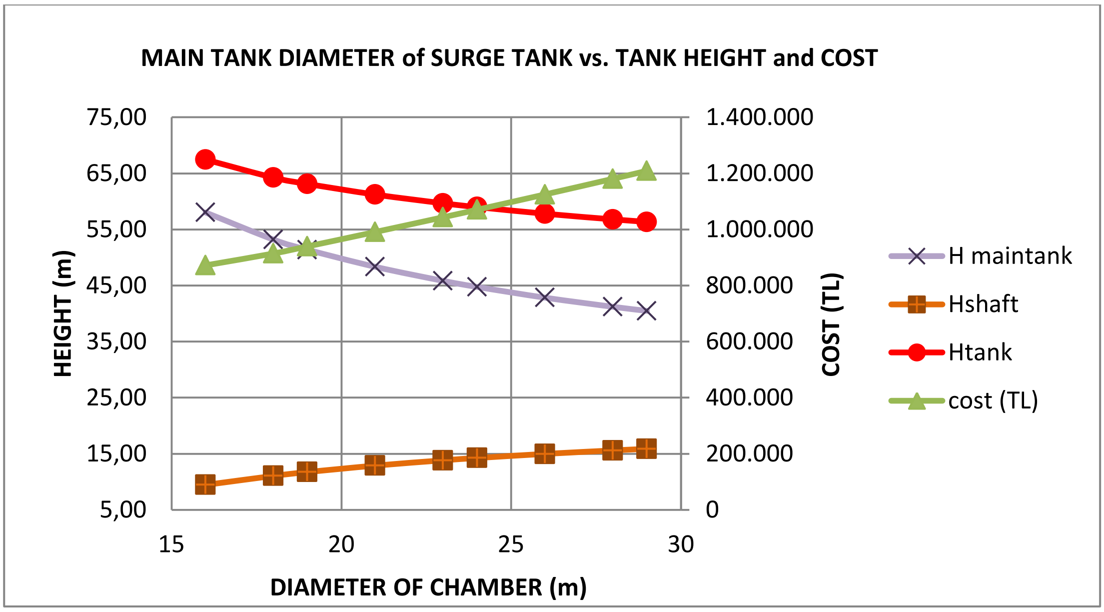

Figure 7.8 The graph of Main Tank diameter vs. Tank height and Cost, for a constant shaft diameter of 6 m, for a shafted surge tank

From the Figures (7.7) and (7.8), it can be seen that when the main tank diameter is increased, the height of maximum upsurge, y_{1max}, the height of maximum downsurge, y_{2max}, are decreased resulting in a decrease in the total height of the tank. However, there exists an inverse proportion between the height of the main tank and the height of the shaft. Height of the main tank is decreased meanwhile the height of the shaft is increased, resulting in the decrease in total height of the tank which can not compensate the increase in cost.

For a constant tank main tank diameter of 18 m and variable shaft diameter;

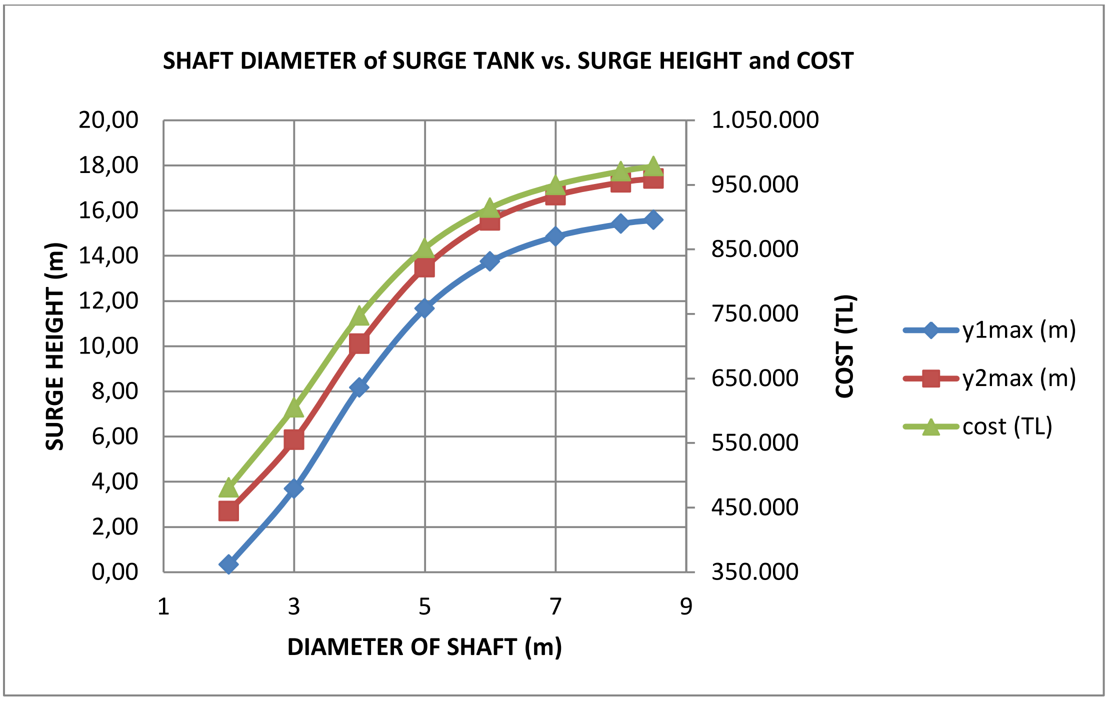

Figure 7.9 The graph of Shaft diameter vs. Surge height and Cost, for a constant tank diameter of 18 m, for a shafted surge tank

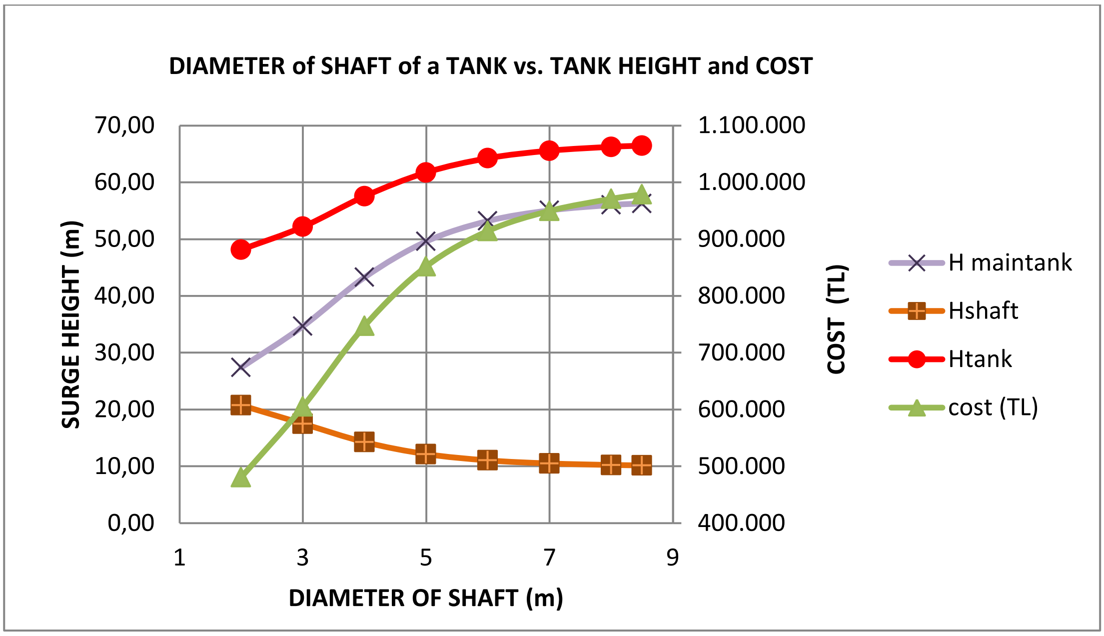

Figure 7.10 The graph of Shaft diameter vs. Tank height and Cost, for a constant tank diameter of 18 m, for a shafted surge tank

From Figures (7.9) and (7.10), it is observed that when the shaft diameter is increased, the height of maximum upsurge, y_{1max}, the height of maximum downsurge, y_{2max}, are increased resulting in an increase in the total height of the tank. However, there exists an inverse proportion between the height of the main tank and the height of the shaft. Height of the main tank is increased meanwhile the height of the shaft is decreased, resulting in the increase in total height of the tank, which also increases the cost.

7.3 Alternative Ways for Comparison

As it is investigated in section (7.2), increasing the diameter of a surge tank, increases the cost. In addition, increasing the diameter of a shaft or an orifice increases the cost of the tank. The aim is to find a comparison parameter. It allows the designer to obtain a case, in which when the diameter is increased, surge heights and the tank height are decreased, resulting in a decrease in the cost of the tank.

7.3.1 Equal Volume

Surge analysis is conducted for a system. Surge heights and corresponding tank heights are calculated. Then the volume of each surge tank having different dimensions is determined. The data are grouped according to their volume. Therefore different groups having same volume but different dimensions are formed.

For a restricted orifice surge tank;

The system parameters that are already known initially are given in Table (7.1);

Table 7.1: The system parameters that are already known, corresponding to Figure (7.11)

H_{resmax} (m)	450
H_{resmin} (m)	425
Q_{min} (m^3/s)	150
Q_{max} (m^3/s)	250
L_t (m)	700
D_t (m)	8.5

Then the system parameters that are calculated accordingly are given in Table (7.2);

Table 7.2: The system parameters that are calculated, corresponding to Figure (7.11)

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	H_{tank} (m)	COST (TL)	VOLUME (m^3)
13	4	14.28	16.18	64.89	745.961	8.613
14	3	6.79	8.90	55.90	612.950	8.604
15	2	0.95	3.29	48.89	582.483	8.640

For a constant volume of 8600 m^3;

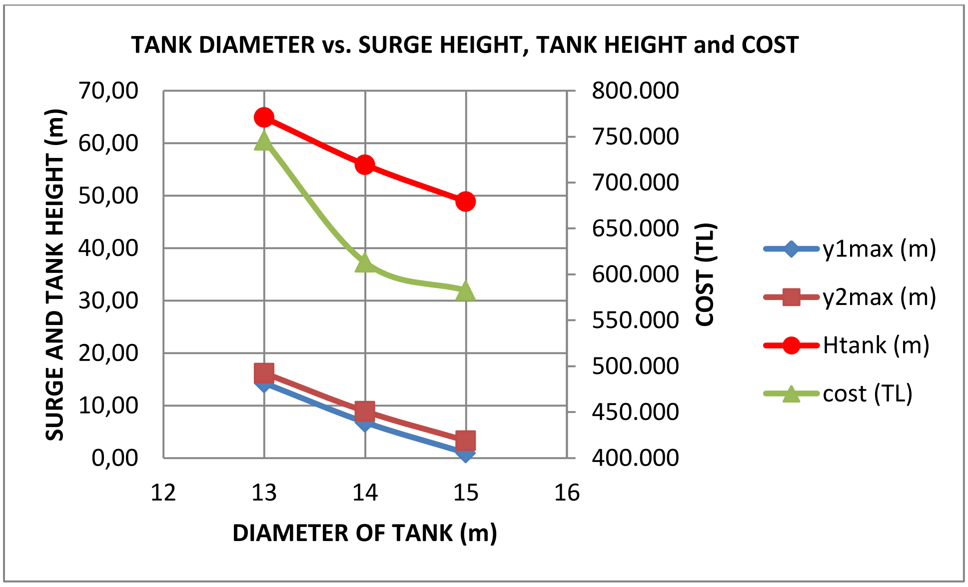

Figure 7.11 The graph of Tank diameter vs. Surge Height, Tank height and Cost, for a constant volume of 8600 m^3, for a restricted orifice surge tank

From figure (7.11), which is drawn based on the values given in Tables (7.1) and (7.2), for a restricted orifice surge tank, it can clearly be seen that, the increase in the tank diameter combined with a decrease in the orifice diameter results in the decrease in y_{1max}, y_{2max}, tank height and cost when the volume is constant.

For a shafted surge tank;

The system parameters that are already known are given in Table (7.3);

Table 7.3: The system parameters that are already known, corresponding to Figure (7.12)

H_{resmax} (m)	450
H_{resmin} (m)	425
Q_{min} (m^3/s)	150
Q_{max} (m^3/s)	250
L_t (m)	700
D_t (m)	8.5

The system parameters that are calculated accordingly are given in Table (7.4);

Table 7.4: The system parameters that are calculated, corresponding to Figure (7.12)

$D_{main\ tank}$ (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	H_{tank} (m)	COST (TL)	VOLUME (m^3)
16	5	13.79	15.62	64.29	807.911	11.007
18	4	8.16	10.11	57.54	747.376	11.192
21	3	2.53	4.71	50.79	666.365	11.289
23	2	0.18	2.57	47.97	608.050	11.142

For a constant volume of 11500 m^3;

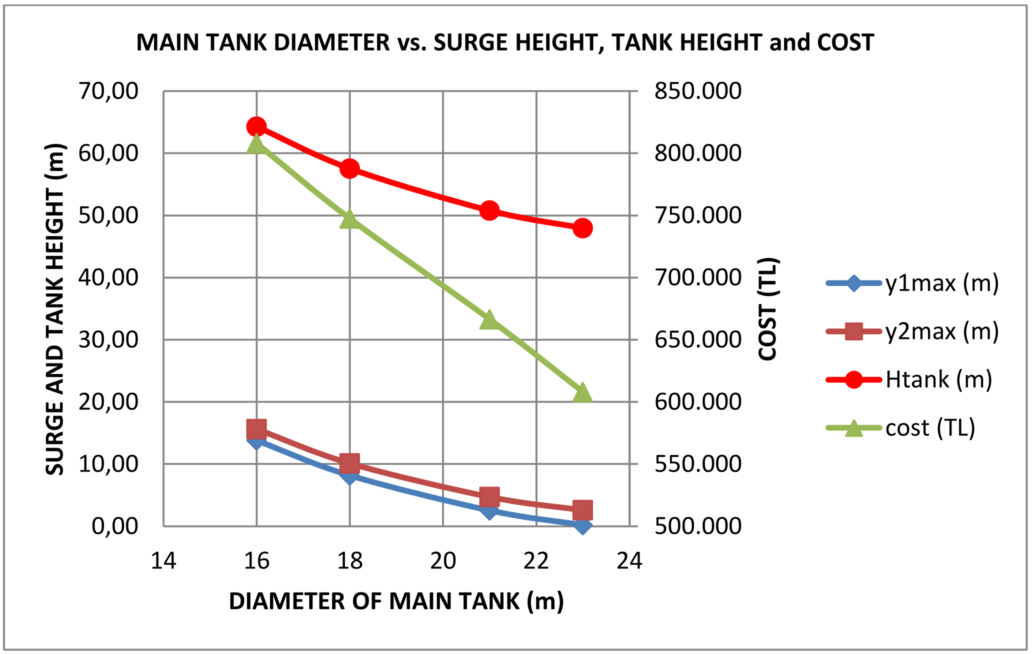

Figure 7.12 The graph of Main Tank diameter vs. Surge Height, Tank height and Cost, for a constant volume of 11500 m^3, for a shafted surge tank

From figure (7.12), which is drawn based on the values given in Tables (7.3) and (7.4) it is obvious that, the increase in the tank diameter combined with a decrease in the shaft diameter, results in the decrease in y_{1max}, y_{2max}, tank height and cost when the volume is constant.

There are two different surge tank parameters; diameter of tank and orifice for a restricted orifice surge tank and diameter of tank and shaft for a shafted surge tank. Therefore, for these kinds of surge tanks, it is possible to catch a point of equilibrium, where the wanted condition can be obtained. However, a simple surge tank only consists of a single parameter, which is the diameter of the tank itself. This is why, there is no possibility of obtaining an equilibrium point corresponding to a constant volume. Because when the tank diameter is increased, the volume of the tank will always increase.

7.3.2 Dimensional Parameters

For a restricted orifice surge tank,

According to the non-dimensional parameter, D_{orf}/D_{tank};

The values for which Figure (7.13) is based on are given in (Appendix B.4).

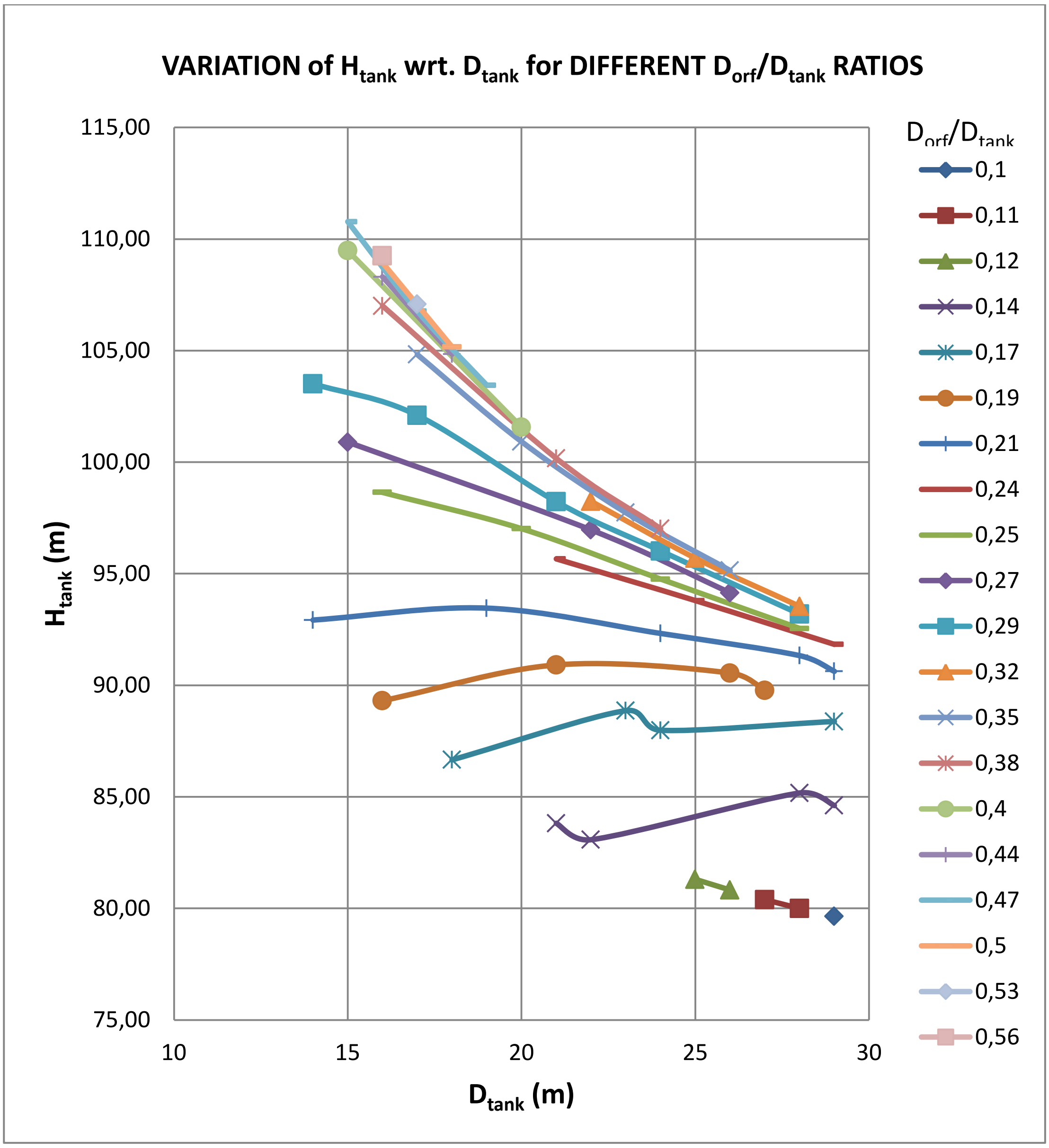

Figure 7.13 The graph of Varioation of Tank height with respect to Tank diameter for different D_{orf}/D_{tank} ratios for a restricted orifice surge tank

From the Figure (7.13), it is observed clearly that, when the tank diameter is increased for different values of D_{orf}/D_{tank}, up to D_{orf}/D_{tank} = 0.21, the tank height fluctuates between closer values, but after D_{orf}/D_{tank} = 0,21, the tank height decreases obviously. Therefore it can be said that, the designer should prefer the values of D_{orf}/D_{tank} larger than 0.21. That way the tank diameter will be increased, resulting in an increase in cost, however, the tank functions much better with a recognizable decrease in tank height. So, it worths increasing the tank height. However, if the designer prefers the values of D_{orf}/D_{tank} less than 0.21 then the tank diameter will be increased, resulting in an increase in cost. However, the tank does not function better. So, it does not worth increasing the tank height.

For a shafted surge tank,

According to the non-dimensional parameter, D_{shaft}/D_{tank};

The values for which Figure (7.14) is based on are given in (Appendix B.5).

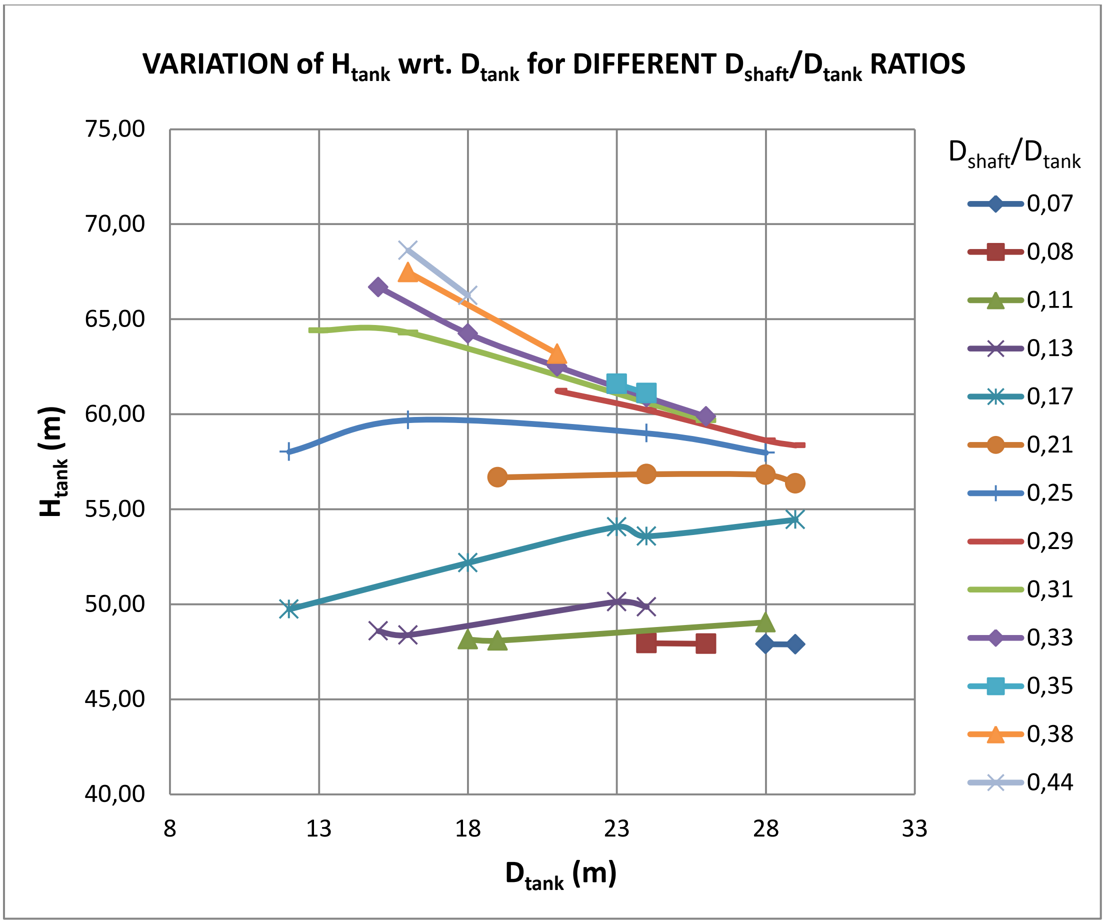

Figure 7.14 The graph of Variation of Tank height with respect to Tank diameter for different D_{shaft}/D_{tank} ratios for a shafted surge tank

A similar case can be observed in Figure (7.14). As explained before the designer should prefer the values of D_{shaft}/D_{tank} larger than 0.25, that way the tank diameter will be increased, resulting in an increase in cost. However, the tank functions much better with a recognizable decrease in tank height. So, it worths increasing the tank height and paying more money.

CHAPTER 8

CONCLUSIONS

For a simple surge tank, two different empirical equations are developed. First one calculates the surge heights for the three different worst case scenarios. Based on these surge analysis ratios, second one calculates the surge tank heights. The coefficients of determination, r^2, obtained from the regression analysis are 0.99 and 0.98 respectively, which shows the high correlation of the equations developed.

For a restricted orifice surge tank, only one empirical equation that calculates the height of a restricted orifice surge tank is obtained. The coefficient of determination, r^2, calculated from the regression analysis is 0.89, which is in the acceptable limits for this kind of tank.

For a shafted surge tank, as the total height of the tank consists of main tank height and the height of shaft, two empirical equations are developed. First one calculates the height of main tank. Based on the first equation, second one calculates the total tank height. The coefficients of determination, r^2, obtained from the regression analysis are 0.90 and 0.90 respectively, which are in acceptable limits for this kind of tank.

When a comparison is done between the coefficients of determination of the equations corresponding to three different surge tanks, r^2 of simple surge tank is higher than the restricted orifice and the shafted surge tank. In a simple surge tank only the tank diameter is assigned and the corresponding tank height is calculated. However, in a restricted orifice surge tank, the diameter of tank and orifice should be assigned in order to calculate the corresponding tank height. Similarly, in a shafted surge tank, the diameter of the main tank and the shaft are assigned to calculate the corresponding heights. Therefore more than one parameter play role in the calculations. This is the reason why r^2 obtained for these kinds of tanks is smaller when compared to a simple surge tank.

For the second part of the design process, which covers the economical aspects of a surge tank, cost functions of three different types of surge tanks are obtained. The behavior of cost function is investigated with respect to the height of the maximum upsurge, downsurge and surge tank height. As a result, it is observed that, as the diameter of the surge tank increases, the height of the maximum upsurge and downsurge decreases resulting in a decrease in the tank height. However, this decrease can not compensate the increase in cost. Therefore, two alternative ways to compensate this increase are suggested.

First, the volumes corresponding to different dimensions for the same system are taken equal. Then for a restricted orifice surge tank, if tank diameter is increased and orifice diameter is decreased, height and cost of the surge tank is decreased. Similarly, for a shafted surge tank if the diameter of the main tank is increased and the diameter of the shaft is decreased, height and cost of the surge tank is decreased. This kind of compensation is not possible for a simple surge tank because simple surge tank has only one parameter, which is the tank diameter that increases the cost when increased.

Second, with the help of non-dimensional parameters D_{orf}/D_{tank} and D_{shaft}/D_{tank} ,a way of comparison is obtained for a restricted orifice and shafted surge tank. The behavior of the tank height and tank diameter are observed for the data groups of different D_{orf}/D_{tank}, $D_{shaft}/D_{tank.}$ It is understood that, for smaller values of D_{orf}/D_{tank} and D_{shaft}/D_{tank} when the tank diameter is increased, the tank height fluctuates between a small range of values, therefore increasing the diameter only increases the cost. There is no significant change in the tank height. However, for larger values of D_{orf}/D_{tank} and D_{shaft}/D_{tank} ,when the tank diameter is increased there is a significant decrease in the tank height. As a result, designing a surge tank with a larger diameter worths paying more money.

Consequently, in the present study a new methodology for determining effective dimensions of a surge tank is offered.

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APPENDIX A

VALUES THAT ARE USED IN THE DEVELOPMENT OF THE EMPIRICAL EQUATIONS

A.1 Values corresponding to Simple Surge Tank Equations

The Data corresponding to six dams are given respectively.

For the dams in Example one and Example two (Cofcof, 2011),

Table A.1.1: The system parameters of the dam in Example two that are already known

Q_{min} (m^3/s)	100
Q_{max} (m^3/s)	240
H_{resmax} (m)	445
H_{resmin} (m)	410
L_t (m)	2000
D_t (m)	9

Table A.1.2: The system parameters of the dam in Example one that are already known

Q_{min} (m^3/s)	150
Q_{max} (m^3/s)	250
H_{resmax} (m)	450
H_{resmin} (m)	425
L_t (m)	700
D_t (m)	8.5

Table A.1.3: The data of the dam in Example two used in the calculations

						H_{tank} obtained from developed equations		
D_{tank} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_t	H_{tank} (m)	Equation(5.4)	Equation(5.5)	Equation(5.6)
17	26.32	28.85	11.94	0.000058266	107	98	116	122
18	24.72	27.27	11.28	0.000058826	105	98	114	119
19	23.29	25.86	10.69	0.000059319	103	99	112	117
20	22.00	24.59	10.16	0.000059752	102	99	111	114
21	20.84	23.43	9.68	0.000060135	101	99	109	112
22	19.78	22.39	9.24	0.000060473	99	99	108	110
23	18.82	21.43	8.84	0.000060775	98	99	106	109
24	17.93	20.56	8.48	0.000061043	97	100	105	107
25	17.12	19.75	8.14	0.000061283	96	100	104	105
26	16.37	19.01	7.83	0.000061499	95	100	103	104
27	15.68	18.32	7.54	0.000061693	94	100	102	103
28	15.03	17.68	7.28	0.000061868	94	100	101	101
29	14.43	17.08	7.03	0.000062027	93	100	100	100
30	13.87	16.53	6.79	0.000062171	92	100	100	99
31	13.35	16.01	6.58	0.000062302	92	100	99	98
32	12.86	15.52	6.37	0.000062422	91	100	98	97
33	12.40	15.06	6.18	0.000062532	90	100	97	96
34	11.97	14.63	6.00	0.000062633	90	100	97	95
35	11.56	14.23	5.83	0.000062726	89	100	96	94

Table A.1.4: The data of the dam in Example one used in the calculations

						H_{tank} obtained from developed equations		
D_{tank} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_t	H_{tank} (m)	Equation(5.4)	Equation(5.5)	Equation(5.6)
18	15.60	17.88	10.65	0.000048896	66	56	58	60
19	14.66	16.96	10.10	0.000049466	65	56	57	59
20	13.82	16.13	9.60	0.000049966	64	56	57	58
21	13.05	15.39	9.15	0.000050406	63	56	56	56
22	12.36	14.70	8.74	0.000050795	63	55	55	55
23	11.72	14.08	8.37	0.000051140	62	55	54	55
24	11.15	13.51	8.02	0.000051446	61	55	54	54
25	10.61	12.99	7.71	0.000051720	60	55	53	53
26	10.12	12.51	7.42	0.000051965	60	55	53	52
27	9.67	12.06	7.15	0.000052186	59	55	52	51
28	9.25	11.64	6.90	0.000052385	59	55	52	51
29	8.86	11.25	6.66	0.000052565	58	55	51	50
30	8.49	10.89	6.45	0.000052729	58	55	51	50
31	8.15	10.56	6.24	0.000052877	58	55	50	49
32	7.83	10.24	6.05	0.000053013	57	55	50	49
33	7.54	9.94	5.87	0.000053137	57	55	50	48

For the dam in Example three (Cofcof, 2011) and Ermenek dam,

Table A.1.5: The system parameters of the dam in Example three that are already known

Q_{min} (m^3/s)	25
Q_{max} (m^3/s)	40
H_{resmax} (m)	350
H_{resmin} (m)	335
L_t (m)	4000
D_t (m)	4

Table A.1.6: The system parameters of Ermenek dam that are already known

Q_{min} (m^3/s)	26
Q_{max} (m^3/s)	104
H_{resmax} (m)	694
H_{resmin} (m)	660
L_t (m)	8064
D_t (m)	5.6

Table A.1.7: The data of the dam in Example three used in the calculations

						H_{tank} obtained from developed equations		
D_{tank} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_t	H_{tank} (m)	Equation(5.4)	Equation(5.5)	Equation(5.6)
10	20.05	26.69	16.43	0.005676620	62	56	57	59
11	17.74	24.37	14.98	0.005691926	59	56	56	58
12	15.83	22.43	13.76	0.005703901	57	55	55	56
13	14.21	20.80	12.74	0.005713419	55	55	54	55
14	12.84	19.41	11.86	0.005721096	53	55	54	54
15	11.66	18.20	11.09	0.005727369	52	54	53	53
16	10.63	17.14	10.43	0.005732557	51	53	52	52
17	9.73	16.22	9.84	0.005736892	50	53	52	52
18	8.94	15.39	9.32	0.005740550	49	52	51	51
19	8.23	14.66	8.85	0.005743665	48	52	51	50
20	7.60	14.01	8.43	0.005746336	47	51	50	50
21	7.04	13.42	8.06	0.005748645	46	50	50	50
22	6.53	12.88	7.71	0.005750654	46	50	50	49
23	6.08	12.40	7.40	0.005752412	45	49	49	49
24	5.66	11.96	7.11	0.005753959	45	48	49	48
25	5.28	11.56	6.85	0.005755327	44	48	49	48
26	4.94	11.19	6.60	0.005756543	44	47	49	48
27	4.63	10.86	6.38	0.005757629	44	46	48	48
28	4.34	10.55	6.17	0.005758601	43	46	48	48
29	4.08	10.27	5.98	0.005759477	43	45	48	48
30	3.84	10.02	5.80	0.005760267	43	44	48	48

Table A.1.8: The data of Ermenek dam used in the calculations

						H_{tank} obtained from developed equations		
D_{tank} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_t	H_{tank} (m)	Equation(5.4)	Equation(5.5)	Equation(5.6)
10	55.28	69.93	17.07	0.001829166	144	128	134	136
11	49.16	63.77	15.53	0.001835692	137	128	131	133
12	44.08	58.66	14.25	0.001840990	131	127	129	129
13	39.78	54.33	13.16	0.001845311	126	127	126	126
14	36.12	50.63	12.23	0.001848864	121	126	124	124
15	32.95	47.43	11.42	0.001851811	118	125	123	122
16	30.20	44.63	10.72	0.001854276	114	124	121	119
17	27.78	42.17	10.09	0.001856355	111	123	119	118
18	25.64	39.98	9.54	0.001858122	109	122	118	116
19	23.73	38.03	9.05	0.001859636	107	121	117	115
20	22.03	36.28	8.60	0.001860942	105	120	115	113
21	20.50	34.70	8.20	0.001862075	103	119	114	112
22	19.11	33.27	7.83	0.001863064	101	118	113	111
23	17.86	31.96	7.50	0.001863933	100	117	112	110
24	16.72	30.77	7.19	0.001864700	98	116	111	109
25	15.68	29.68	6.91	0.001865379	97	114	110	108
26	14.73	28.68	6.65	0.001865985	96	113	110	107
27	13.85	27.76	6.41	0.001866526	95	112	109	107
28	13.05	26.90	6.18	0.001867012	94	111	108	106
29	12.31	26.12	5.97	0.001867450	93	109	107	106
30	11.62	25.39	5.78	0.001867846	92	108	107	105

For Atasu and Gezende dams,

Table A.1.9: The system parameters of Atasu dam that are already known

Q_{min} (m^3/s)	8
Q_{max} (m^3/s)	32
H_{resmax} (m)	319.05
H_{resmin} (m)	256
L_t (m)	2600
D_t (m)	3.3

Table A.1.10: The system parameters of Gezende dam that are already known

Q_{min} (m^3/s)	29.25
Q_{max} (m^3/s)	117
H_{resmax} (m)	333
H_{resmin} (m)	310
L_t (m)	8629
D_t (m)	5.6

Table A.1.11: The data of Atasu dam used in the calculations

						H_{tank} obtained from developed equations		
D_{tank} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_t	H_{tank} (m)	Equation(5.4)	Equation(5.5)	Equation(5.6)
6	26.81	34.63	8.44	0.010387090	110	86	90	92
7	22.06	29.87	7.24	0.010469581	104	85	87	88
8	18.51	26.32	6.35	0.010527924	100	84	84	85
9	15.78	23.56	5.65	0.010570108	97	83	82	82
10	13.61	21.36	5.09	0.010601372	94	82	80	80
11	11.86	19.56	4.64	0.010625089	92	80	79	78
12	10.42	18.07	4.26	0.010643462	90	79	77	76
13	9.21	16.82	3.93	0.010657959	89	77	76	75
14	8.19	15.76	3.66	0.010669586	88	76	75	74
15	7.33	14.84	3.42	0.010679046	87	74	74	73
16	6.58	14.05	3.21	0.010686842	86	73	73	73
17	5.93	13.37	3.03	0.010693339	85	71	72	72
18	5.37	12.77	2.86	0.010698809	84	70	72	72
19	4.88	12.25	2.72	0.010703456	84	68	71	72
20	4.45	11.80	2.58	0.010707437	83	67	70	72
21	4.06	11.42	2.46	0.010710872	83	65	70	72
22	3.73	11.12	2.36	0.010713857	82	64	69	72
23	3.43	10.97	2.26	0.010716467	82	62	68	74
24	3.16	10.96	2.17	0.010718761	82	61	68	77
25	2.92	10.95	2.08	0.010720789	81	60	67	79
26	2.70	10.92	2.01	0.010722590	81	59	67	82

Table A.1.12: The data of Gezende dam used in the calculations

D_{tank} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_t	H_{tank} (m)	H_{tank} obtained from developed equations		
						Equation(5.4)	Equation(5.5)	Equation(5.6)
17	30.44	49.59	11.77	0.001972911	117	117	114	112
18	27.98	47.06	11.13	0.001974678	114	116	112	111
19	25.80	44.81	10.55	0.001976192	112	115	111	109
20	23.86	42.79	10.03	0.001977498	109	113	110	108
21	22.12	40.97	9.56	0.001978631	107	112	109	107
22	20.55	39.33	9.14	0.001979620	105	111	108	106
23	19.13	37.83	8.75	0.001980489	104	109	107	106
24	17.84	36.47	8.39	0.001981256	102	108	106	105
25	16.67	35.23	8.06	0.001981935	101	106	105	104
26	15.60	34.09	7.76	0.001982541	99	105	105	104
27	14.62	33.05	7.48	0.001983082	98	103	104	103
28	13.73	32.10	7.22	0.001983568	97	102	103	103
29	12.91	31.23	6.98	0.001984006	96	101	102	103
30	12.15	30.43	6.75	0.001984402	95	99	102	103
31	11.46	29.70	6.54	0.001984761	94	98	101	103
32	10.81	29.04	6.34	0.001985088	94	96	101	103
33	10.22	28.45	6.16	0.001985386	93	95	100	103

A.2 Values corresponding to Restricted Orifice Surge Tank Equations

The Data corresponding to six dams are given respectively.

For the dam in Example two (Cofcof, 2011),

Table A.2.1: The system parameters of the dam in Example two that are already known

Q_{min} (m^3/s)	100
Q_{max} (m^3/s)	240
c_t	0.000051742
H_{resmax} (m)	445
H_{resmin} (m)	410
L_t (m)	2000
D_t (m)	9

Table A.2.2: The data of the dam in Example two used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obtained (m)
14	3	14.52	16.98	9.58	0.001309386	93	83
14	4	23.34	25.6	12.43	0.000380999	104	91
14	5	28.33	30.56	13.63	0.000139016	110	92
14	6	30.68	32.92	14.11	0.000057362	112	93
15	3	12.89	15.37	8.74	0.001320942	91	82
15	4	21.16	23.43	11.47	0.000387272	101	89
15	5	25.99	28.21	12.65	0.000142844	107	91
15	6	28.32	30.55	13.14	0.000059862	109	92
15	7	29.40	31.64	13.34	0.000026767	111	92
16	3	11.51	14.00	8.01	0.001330452	89	80
16	4	19.29	21.55	10.64	0.000392459	99	88
16	5	23.95	26.17	11.80	0.000146031	104	90
16	6	26.25	28.48	12.28	0.000061961	107	91
16	7	27.34	29.58	12.49	0.000028210	108	91
17	4	17.66	19.93	9.90	0.000396795	97	87
17	5	22.17	24.37	11.05	0.000148708	102	90
17	6	24.44	26.66	11.53	0.000063737	105	90
17	7	25.53	27.76	11.74	0.000029443	106	91
18	3	9.30	11.81	6.83	0.001345032	87	77
18	5	20.59	22.80	10.38	0.000150976	100	89
18	6	22.83	25.04	10.86	0.000065251	103	89

Table A.2.2.continued: The data of the dam in Example two used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obtained (m)
18	7	23.91	26.14	11.08	0.000030502	104	90
19	3	8.40	10.92	6.35	0.001350687	86	76
19	4	14.96	17.25	8.68	0.000403567	93	85
19	6	21.39	23.60	10.26	0.000066550	101	89
19	7	22.47	24.70	10.48	0.000031415	102	89
20	3	7.62	10.15	5.92	0.001355529	85	75
20	4	13.84	16.13	8.17	0.000406239	92	84
20	5	17.93	20.14	9.25	0.000154582	97	87
20	7	21.18	23.40	9.94	0.000032209	101	89
21	3	6.93	9.47	5.54	0.001359705	84	74
21	4	12.84	15.14	7.70	0.000408548	91	83
21	5	16.80	19.01	8.77	0.000156027	96	86
21	6	18.94	21.14	9.24	0.000068647	98	88
22	3	6.31	8.86	5.19	0.001363332	83	73
22	4	11.94	14.24	7.28	0.000410557	90	82
22	5	15.79	17.99	8.33	0.000157286	94	86
22	6	17.89	20.09	8.80	0.000069500	97	87
22	7	18.95	21.17	9.02	0.000033508	98	88
23	3	5.77	8.32	4.89	0.001366502	82	72
23	4	11.14	13.44	6.90	0.000412315	89	82
23	5	14.86	17.07	7.93	0.000158391	93	85

Table A.2.2.continued: The data of the dam in Example two used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
23	6	16.93	19.13	8.40	0.000070249	96	86
23	7	17.99	20.20	8.62	0.000034044	97	87
24	4	10.40	12.71	6.56	0.000413861	88	81
24	5	14.02	16.23	7.57	0.000159364	92	85
24	6	16.05	18.25	8.03	0.000070911	95	86
24	7	17.10	19.31	8.25	0.000034518	96	87
25	3	4.83	7.40	4.35	0.001371749	81	70
25	5	13.25	15.46	7.23	0.000160226	91	84
25	6	15.25	17.44	7.69	0.000071498	94	85
25	7	16.29	18.49	7.91	0.000034939	95	86
26	3	4.44	7.00	4.12	0.001373935	81	69
26	4	9.13	11.45	5.95	0.000416446	86	79
26	6	14.51	16.70	7.38	0.000072022	93	85
26	7	15.54	17.74	7.60	0.000035315	94	86
27	3	4.07	6.65	3.91	0.001375884	80	69
27	4	8.57	10.89	5.68	0.000417531	86	79
27	5	11.89	14.10	6.64	0.000161679	90	83
27	7	14.85	17.05	7.31	0.000035653	93	85
28	3	3.75	6.32	3.72	0.001377630	80	68
28	4	8.06	10.39	5.43	0.000418504	85	78
28	5	11.29	13.50	6.37	0.000162294	89	82

Table A.2.2.continued: The data of the dam in Example two used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
28	6	13.19	15.38	6.82	0.000072911	91	84
29	3	3.45	6.03	3.54	0.001379200	80	67
29	4	7.59	9.92	5.20	0.000419379	85	77
29	5	10.73	12.94	6.13	0.000162848	88	82
29	6	12.60	14.79	6.58	0.000073290	91	83
29	7	13.61	15.80	6.79	0.000036230	92	84

For the dam in Example three (Cofcof, 2011),

Table A.2.3: The system parameters of the dam in Example three that are already known

Q_{min} (m^3/s)	25
Q_{max} (m^3/s)	40
c_t	0.005448880
H_{resmax} (m)	350
H_{resmin} (m)	335
L_t (m)	4000
D_t (m)	4

Table A.2.4: The data of the dam in Example three used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
9	2	18.37	24.65	16.08	0.006293446	60	58
10	2	15.66	21.91	14.32	0.006386023	57	57
10	3	19.34	25.67	16.02	0.001032173	61	60
10	4	20.05	26.42	16.33	0.000227740	62	62
11	2	13.49	19.71	12.89	0.006455105	54	56
11	3	17.04	23.33	14.55	0.001061421	58	59
11	4	17.74	24.08	14.86	0.000243046	59	61
12	2	11.71	17.90	11.7	0.006507981	52	55
12	3	15.13	21.38	13.33	0.001083999	56	59
12	4	15.83	22.13	13.64	0.000255021	57	61
13	2	10.23	16.40	10.71	0.006549330	50	54
13	3	13.53	19.75	12.30	0.001101770	54	58
13	4	14.21	20.49	12.61	0.000264540	55	60
14	2	8.99	15.13	9.86	0.006582263	49	53
14	3	12.17	18.35	11.42	0.001115995	53	58
14	4	12.84	19.09	11.73	0.000272216	53	60
15	2	7.95	14.06	9.14	0.006608912	48	53
15	3	11.00	17.15	10.65	0.001127551	51	57
15	4	11.66	17.87	10.97	0.000278489	52	59
16	2	7.05	13.14	8.51	0.006630775	46	52
16	3	9.99	16.10	9.99	0.001137061	50	57
16	4	10.63	16.81	10.30	0.000283667	51	59

Table A.2.4.continued: The data of the dam in Example three used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
17	2	6.28	12.35	7.96	0.006648931	46	52
17	3	9.10	15.18	9.4	0.001144980	49	56
17	4	9.73	15.88	9.71	0.000288012	50	58
18	2	5.62	11.66	7.47	0.006664171	45	51
18	3	8.32	14.36	8.88	0.001151641	48	56
18	4	8.94	15.06	9.19	0.000291671	49	58
19	2	5.04	11.07	7.04	0.006677087	44	51
19	3	7.63	13.64	8.42	0.001157296	47	55
19	4	8.23	14.32	8.72	0.000294785	48	58
20	2	4.54	10.56	6.66	0.006688128	43	50
20	3	7.02	13.00	8.00	0.001162138	46	55
20	4	7.60	13.67	8.30	0.000297457	47	57
21	2	4.10	10.12	6.31	0.006697638	43	50
21	3	6.47	12.42	7.62	0.001166314	46	55
21	4	7.04	13.07	7.92	0.000299766	46	57
22	2	3.72	9.75	6.00	0.006705889	42	49
22	3	5.98	11.90	7.28	0.001169941	45	54
22	4	6.53	12.54	7.57	0.000301774	46	57
23	2	3.38	9.43	5.73	0.006713093	42	49
23	3	5.54	11.43	6.97	0.001173111	45	54
23	4	6.08	12.05	7.26	0.000303532	45	56

Table A.2.4.continued: The data of the dam in Example three used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
24	2	3.09	9.18	5.47	0.006719419	42	49
24	3	5.14	11.01	6.68	0.001175897	44	54
24	4	5.66	11.61	6.97	0.000305079	45	56
25	2	2.83	8.98	5.24	0.006725005	41	48
25	3	4.78	10.63	6.42	0.001178358	44	53
25	4	5.28	11.21	6.71	0.000306447	44	56
26	2	2.60	8.83	5.04	0.006729961	41	48
26	3	4.45	10.28	6.18	0.001180544	43	53
26	4	4.94	10.84	6.46	0.000307603	44	56
27	2	2.40	8.75	4.85	0.006734379	41	48
27	3	4.16	9.97	5.96	0.001182493	43	53
27	4	4.63	10.51	6.24	0.000308749	44	55
28	2	2.22	8.72	4.67	0.006738334	41	48
28	3	3.89	9.69	5.75	0.001184239	43	53
28	4	4.34	10.20	6.03	0.000309722	43	55

For Ermenek dam,

Table A.2.5: The system parameters of Ermenek dam that are already known

Q_{min} (m^3/s)	26
Q_{max} (m^3/s)	104
c_t	0.001789582
H_{resmax} (m)	694
H_{resmin} (m)	660
L_t (m)	8064
D_t (m)	5.6

Table A.2.6: The data of Ermenek dam used in the calculations

D_{tank} (m)	**D_{orf} (m)**	**y_{1max} (m)**	**y_{2max} (m)**	**y_{2min} (m)**	**c_{orf}**	**H_{tank} (m)**	**H_{tank} obt. (m)**
7	2	57.20	71.74	21.92	0.006247763	147	126
8	2	46.13	60.62	18.88	0.006431131	133	123
9	2	37.82	52.31	16.53	0.006559032	123	120
9	3	56.54	70.70	18.47	0.001111472	146	124
10	2	31.40	45.89	14.67	0.006651610	116	118
10	3	49.05	63.09	16.58	0.001150211	137	123
10	4	53.71	67.94	16.94	0.000294137	143	125

Table A.2.6.continued: The data of Ermenek dam used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
11	2	26.32	40.82	13.16	0.006720691	110	116
11	3	42.97	56.92	15.03	0.001179459	130	121
11	4	47.57	61.70	15.39	0.000309443	135	124
12	2	22.24	36.75	11.90	0.006773567	105	114
12	3	37.96	51.83	13.73	0.001202038	124	119
12	4	42.47	56.52	14.10	0.000321418	129	122
13	2	18.92	33.42	10.85	0.006814916	101	112
13	3	33.76	47.57	12.64	0.001219809	119	118
13	4	38.18	52.16	13.01	0.000330936	124	121
14	2	16.18	30.68	9.95	0.006847849	97	110
14	3	30.20	43.94	11.71	0.001234033	114	117
14	4	34.52	48.43	12.08	0.000338613	119	120
15	2	13.90	28.40	9.18	0.006874498	95	109
15	3	27.16	40.83	10.90	0.001245589	111	116
15	4	31.37	45.21	11.27	0.000344886	116	119
16	2	12.00	26.50	8.51	0.006896361	92	107
16	3	24.52	38.13	10.19	0.001255100	107	115
16	4	28.63	42.40	10.56	0.000350073	112	118
17	2	10.40	24.91	7.92	0.006914517	91	106
17	3	22.23	35.77	9.57	0.001263018	105	114
17	4	26.23	39.94	9.94	0.000354409	110	117

Table A.2.6.continued: The data of Ermenek dam used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
18	2	9.06	23.59	7.40	0.006929758	89	105
18	3	20.22	33.70	9.02	0.001269679	102	113
18	4	24.11	37.75	9.38	0.000358067	107	116
19	2	7.93	22.50	6.94	0.006942674	88	103
19	3	18.45	31.87	8.52	0.001275335	100	112
19	4	22.23	35.81	8.89	0.000361181	105	115
20	2	6.98	21.62	6.53	0.006953714	86	102
20	3	16.88	30.24	8.08	0.001280176	98	111
20	4	20.56	34.07	8.44	0.000363853	103	114
21	2	6.18	20.92	6.16	0.006963225	85	101
21	3	15.48	28.79	7.68	0.001284352	97	110
21	4	19.05	32.50	8.04	0.000366162	101	114
22	2	5.50	20.39	5.83	0.006971476	85	100
22	3	14.23	27.49	7.31	0.001287979	95	109
22	4	17.70	31.09	7.67	0.000368171	99	113
23	2	4.93	20.02	5.52	0.006978679	84	99
23	3	13.11	26.33	6.98	0.001291149	94	109
23	4	16.47	29.80	7.33	0.000369929	98	112
24	2	4.45	19.77	5.25	0.006985005	83	98
24	3	12.11	25.28	6.67	0.001293935	93	108
24	4	15.36	28.63	7.03	0.000371476	97	112

Table A.2.6.continued: The data of Ermenek dam used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
25	2	4.04	19.61	4.99	0.006990591	83	97
25	3	11.20	24.34	6.39	0.001296397	92	107
25	4	14.35	27.56	6.74	0.000372844	95	111
26	2	3.69	19.51	4.76	0.006995547	83	96
26	3	10.39	23.49	6.14	0.001298582	91	106
26	4	13.43	26.59	6.48	0.000374060	94	110
27	2	3.39	19.45	4.55	0.006999965	82	96
27	3	9.65	22.73	5.90	0.001300532	90	106
27	4	12.59	25.69	6.24	0.000375145	93	110
28	2	3.13	19.41	4.35	0.007003920	82	95
28	3	8.98	22.05	5.67	0.001302278	89	105
28	4	11.81	24.87	6.02	0.000376118	92	109
29	2	2.90	19.38	4.17	0.007007474	82	94
29	3	8.37	21.44	5.47	0.001303847	88	105
29	4	11.10	24.12	5.81	0.000376994	91	109

For Gezende dam,

Table A.2.7: The system parameters of Gezende dam that are already known

Q_{min} (m^3/s)	29.25
Q_{max} (m^3/s)	117
c_t	0.001906138
H_{resmax} (m)	333
H_{resmin} (m)	310
L_t (m)	8629
D_t (m)	5.6

Table A.2.8: The data of Gezende dam used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
8	2	50.19	69.66	21.79	0.006431131	141	134
9	2	40.71	60.17	19.07	0.006559032	130	131
10	2	33.43	52.89	16.90	0.006651610	121	128
10	3	54.55	73.35	19.27	0.001150211	146	134
10	4	60.28	79.33	19.72	0.000294137	153	137
10	5	61.86	81.03	19.84	0.000085625	155	140
11	2	27.72	47.17	15.15	0.006720691	114	126
11	3	47.54	66.20	17.46	0.001179459	138	132
11	4	53.16	72.07	17.92	0.000309443	145	135
11	5	54.76	73.79	18.04	0.000094478	146	138
12	2	23.16	42.61	13.70	0.006773567	109	124
12	3	41.77	60.31	15.96	0.001202038	131	131
12	4	47.27	66.06	16.42	0.000321418	137	134
12	5	48.86	67.78	16.54	0.000101545	139	137
13	2	19.49	38.92	12.48	0.006814916	104	122
13	3	36.95	55.39	14.69	0.001219809	125	129
13	4	42.31	60.99	15.15	0.000330936	132	133
13	5	43.89	62.71	15.27	0.000107244	133	135
14	2	16.49	35.92	11.44	0.006847849	101	120
14	3	32.88	51.21	13.60	0.001234033	120	128
14	4	38.09	56.66	14.06	0.000338613	126	131
14	5	39.66	58.38	14.19	0.000111889	128	134

Table A.2.8.continued: The data of Gezende dam used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
15	2	14.04	33.48	10.55	0.006874498	98	118
15	3	29.41	47.63	12.66	0.001245589	116	127
15	4	34.47	52.93	13.12	0.000344886	122	130
15	5	36.01	54.64	13.25	0.000115718	124	133
16	2	12.02	31.49	9.78	0.006896361	95	117
16	3	26.41	44.54	11.84	0.001255100	112	125
16	4	31.33	49.69	12.30	0.000350073	118	129
16	5	32.84	51.37	12.42	0.000118904	120	132
17	2	10.36	29.90	9.10	0.006914517	93	115
17	3	23.82	41.85	11.12	0.001263018	109	124
17	4	28.58	46.84	11.57	0.000354409	115	128
17	5	30.07	48.50	11.70	0.000121581	117	131
18	2	8.99	28.66	8.50	0.006929758	92	114
18	3	21.55	39.50	10.47	0.001269679	107	123
18	4	26.16	44.32	10.93	0.000358067	112	127
18	5	27.62	45.96	11.05	0.000123849	114	130
19	2	7.86	27.73	7.97	0.006942674	90	112
19	3	19.56	37.43	9.90	0.001275335	104	122
19	4	24.02	42.09	10.35	0.000361181	110	126
19	5	25.45	43.70	10.48	0.000125787	111	129
20	2	6.93	27.08	7.49	0.006953714	89	111

Table A.2.8.continued: The data of Gezende dam used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
20	3	17.81	35.60	9.38	0.001280176	102	121
20	4	22.12	40.09	9.83	0.000363853	107	125
20	5	23.51	41.67	9.96	0.000127455	109	128
21	2	6.16	26.65	7.07	0.006963225	88	110
21	3	16.26	33.98	8.91	0.001284352	100	120
21	4	20.41	38.29	9.36	0.000366162	105	124
21	5	21.77	39.85	9.49	0.000128900	107	128
22	2	5.52	26.40	6.68	0.006971476	87	109
22	3	14.89	32.55	8.49	0.001287979	99	119
22	4	18.89	36.68	8.93	0.000368171	103	124
22	5	20.21	38.20	9.06	0.000130159	105	127
23	2	4.98	26.26	6.33	0.006978679	87	108
23	3	13.66	31.28	8.10	0.001291149	97	119
23	4	17.51	35.22	8.54	0.000369929	102	123
23	5	18.80	36.71	8.67	0.000131264	103	126
24	2	4.53	26.18	6.02	0.006985005	86	107
24	3	12.57	30.16	7.75	0.001293935	96	118
24	4	16.27	33.90	8.19	0.000371476	100	122
24	5	17.52	35.35	8.31	0.000132237	102	125
25	2	4.15	26.13	5.73	0.006990591	86	106
25	3	11.59	29.18	7.42	0.001296397	95	117

Table A.2.8.continued: The data of Gezende dam used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
25	4	15.14	32.70	7.86	0.000372844	99	122
25	5	16.36	34.11	7.98	0.000133099	100	125
26	2	3.81	26.11	5.46	0.006995547	85	105
26	3	10.71	28.32	7.12	0.001298582	94	116
26	4	14.12	31.62	7.55	0.000374060	98	121
26	5	15.30	32.98	7.68	0.000133866	99	124
27	2	3.52	26.09	5.22	0.006999965	85	104
27	3	9.93	27.59	6.84	0.001300532	93	116
27	4	13.19	30.63	7.27	0.000375145	97	120
27	5	14.33	31.94	7.40	0.000134552	98	124
28	2	3.27	26.06	4.99	0.007003920	85	103
28	3	9.22	26.99	6.59	0.001302278	92	115
28	4	12.34	29.74	7.01	0.000376118	96	120
28	5	13.44	30.99	7.14	0.000135167	97	123
29	2	3.04	25.99	4.78	0.007007474	84	102
29	3	8.58	26.52	6.35	0.001303847	91	115
29	4	11.56	28.93	6.77	0.000376994	95	119
29	5	12.63	30.13	6.90	0.000135721	96	122

For Atasu and Çine dams,

Table A.2.9: The system parameters of Atasu dam that are already known

Q_{min} (m^3/s)	8
Q_{max} (m^3/s)	32
c_t	0.010048126
H_{resmax} (m)	319.05
H_{resmin} (m)	256
L_t (m)	2600
D_t (m)	3.3

Table A.2.10: The system parameters of Çine dam that are already known

Q_{min} (m^3/s)	9.75
Q_{max} (m^3/s)	35
c_t	0.004692479
H_{resmax} (m)	264.8
H_{resmin} (m)	205
L_t (m)	2926
D_t (m)	3.9

Table A.2.11: The data of Atasu dam used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
20	3	4.32	11.18	2.54	0.001049054	83	58
20	3.3	4.45	11.32	2.55	0.000659311	83	59
21	3	3.94	10.80	2.42	0.001053230	83	58
21	3.3	4.06	10.93	2.43	0.000662746	83	58
22	3	3.61	10.50	2.31	0.001056857	82	58
22	3.3	3.73	10.61	2.32	0.000665731	82	58
23	3	3.32	10.30	2.21	0.001060027	82	57
23	3.3	3.43	10.36	2.23	0.000668341	82	58
24	3	3.06	10.28	2.12	0.001062813	82	57
24	3.3	3.16	10.29	2.14	0.000670635	82	58
25	3	2.82	10.27	2.04	0.001065274	81	57
25	3.3	2.92	10.28	2.05	0.000672663	81	57
26	3	2.61	10.25	1.96	0.001067460	81	56
26	3.3	2.70	10.26	1.97	0.000674464	81	57
27	3	2.43	10.22	1.89	0.001069409	81	56
27	3.3	2.51	10.23	1.90	0.000676071	81	57
28	3	2.26	10.19	1.82	0.001071155	81	56
28	3.3	2.34	10.19	1.84	0.000677510	81	57

Table A.2.12: The data of Çine dam used in the calculations

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	c_{orf}	H_{tank} (m)	H_{tank} obt. (m)
20	3	5.82	9.81	2.73	0.001149621	80	55
20	3.9	6.27	10.31	2.77	0.000330514	81	56
21	3	5.38	9.36	2.59	0.001153797	80	54
21	3.9	5.83	9.85	2.64	0.000332948	80	56
22	3	4.99	8.95	2.48	0.001157424	79	54
22	3.9	5.43	9.44	2.52	0.000335065	80	56
23	3	4.64	8.58	2.37	0.001160593	79	54
23	3.9	5.06	9.06	2.41	0.000336917	80	55
24	3	4.32	8.25	2.27	0.001163379	79	53
24	3.9	4.74	8.71	2.32	0.000338547	79	55
25	3	4.04	7.94	2.18	0.001165841	78	53
25	3.9	4.44	8.40	2.22	0.000339988	79	55
26	3	3.77	7.66	2.09	0.001168027	78	53
26	3.9	4.16	8.11	2.14	0.000341269	78	54
27	3	3.53	7.41	2.01	0.001169976	78	53
27	3.9	3.91	7.84	2.06	0.000342412	78	54
28	3	3.31	7.17	1.94	0.001171722	77	52
28	3.9	3.68	7.59	1.99	0.000343436	78	54
29	3	3.11	6.96	1.87	0.001173292	77	52
29	3.9	3.47	7.37	1.92	0.000344358	78	54

A.3 Values corresponding to Shafted Surge Tank Equations

A.3.1 Values of Main Tank Height corresponding to Shafted Surge Tank Equations

The Data corresponding to four dams are given respectively.

For the dams in Example one and Example two (Cofcof, 2011),

Table A.3.1.1: The system parameters of the dam in Example one that are already known

Q_{min} (m^3/s)	150
Q_{max} (m^3/s)	250
c_t	0.000039339
H_{resmax} (m)	450
H_{resmin} (m)	425
L_t (m)	700
D_t (m)	8.5

Table A.3.1.2: The system parameters of the dam in Example two that are already known

Q_{min} (m^3/s)	100
Q_{max} (m^3/s)	240
H_{resmax} (m)	445
H_{resmin} (m)	410
L_t (m)	2000
D_t (m)	9

Table A.3.1.3: The data of the dam in Example one used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
9	2	3.83	6.15	4.97	0.007966640	36	52
10	2	2.89	5.22	4.19	0.008059217	33	48
10	3	12.00	14.08	10.36	0.001363717	52	58
12	2	1.65	3.99	3.13	0.008181175	31	42
12	3	8.56	10.66	7.93	0.001415544	45	51
13	2	1.24	3.58	2.75	0.008222523	30	39
13	3	7.33	9.45	7.05	0.001433314	42	48
13	4	13.88	15.79	10.80	0.000401109	55	55
15	2	0.69	3.04	2.20	0.008282106	28	35
15	3	5.49	7.63	5.71	0.001459095	38	43
15	4	11.05	12.98	8.97	0.000415059	49	50
15	5	15.78	16.91	10.94	0.000150208	57	55
16	2	0.52	2.87	2.00	0.008303969	28	34
16	3	4.79	6.94	5.19	0.001468606	37	41
16	4	9.95	11.88	8.25	0.000420246	47	48
16	5	13.79	15.62	10.14	0.000153394	54	53
16	6	16.43	17.80	11.09	0.000064089	58	57
16	7	17.39	18.93	11.54	0.000028720	60	60
18	2	0.33	2.69	1.67	0.008337365	27	31

Table A.3.1.3.continued: The data of the dam in Example one used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
18	3	3.69	5.85	4.37	0.001483185	35	38
18	4	8.16	10.11	7.07	0.000428240	43	44
18	5	11.66	13.49	8.83	0.000158340	50	49
18	6	13.74	15.56	9.75	0.000067379	53	53
18	7	14.85	16.67	10.20	0.000031012	55	56
18	8	15.41	17.25	10.42	0.000014727	56	58
18	8.5	15.58	17.42	10.48	0.000010113	56	59
19	2	0.28	2.65	1.55	0.008350281	27	29
19	3	3.25	5.42	4.03	0.001488841	34	36
19	4	7.44	9.39	6.58	0.000431354	42	42
19	5	10.78	12.61	8.28	0.000160278	48	47
19	6	12.81	14.62	9.18	0.000068678	51	51
19	7	13.90	15.72	9.63	0.000031925	53	54
19	8	14.47	16.30	9.86	0.000015391	54	56
19	8.5	14.64	16.48	9.92	0.000010684	54	57
21	2	0.22	2.60	1.35	0.008370832	27	27
21	3	2.53	4.71	3.48	0.001497858	32	34
21	4	6.23	8.19	5.76	0.000436335	39	39
21	5	9.29	11.13	7.35	0.000163390	45	43
21	6	11.23	13.03	8.22	0.000070776	48	47

Table A.3.1.3.continued: The data of the dam in Example one used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
21	7	12.29	14.11	8.67	0.000033411	50	50
21	8	12.86	14.68	8.89	0.000016479	51	53
21	8.5	13.03	14.86	8.96	0.000011624	51	54
23	2	0.18	2.57	1.20	0.008386287	27	25
23	3	1.98	4.17	3.05	0.001504655	31	31
23	4	5.26	7.24	5.11	0.000440101	37	36
23	5	8.09	9.93	6.59	0.000165754	43	41
23	6	9.93	11.74	7.43	0.000072378	46	44
23	7	10.97	12.78	7.87	0.000034554	48	47
23	8	11.53	13.35	8.09	0.000017324	49	50
23	8.5	11.70	13.53	8.16	0.000012357	49	50
24	2	0.16	2.56	1.15	0.008392613	27	25
24	3	1.76	3.94	2.87	0.001507441	31	30
24	4	4.86	6.84	4.83	0.000441648	37	35
24	5	7.57	9.42	6.26	0.000166727	42	39
24	6	9.37	11.17	7.09	0.000073039	45	43
24	7	10.39	12.20	7.52	0.000035027	46	46
24	8	10.95	12.77	7.75	0.000017676	47	48
24	8.5	11.13	12.94	7.82	0.000012664	48	49

Table A.3.1.3.continued: The data of the dam in Example one used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
26	2	0.14	2.54	1.06	0.008403155	26	23
26	3	1.38	3.57	2.55	0.001512088	30	29
26	4	4.15	6.14	4.34	0.000444233	35	33
26	5	6.67	8.52	5.68	0.000168357	40	37
26	6	8.38	10.18	6.48	0.000074150	43	40
26	7	9.38	11.18	6.91	0.000035825	45	43
26	8	9.93	11.74	7.13	0.000018271	45	46
26	8.5	10.10	11.92	7.20	0.000013183	46	46
28	2	0.12	2.52	1.00	0.008411527	26	22
28	3	1.08	3.28	2.30	0.001515784	29	27
28	4	3.57	5.57	3.93	0.000446291	34	31
28	5	5.92	7.77	5.19	0.000169657	38	35
28	6	7.55	9.34	5.96	0.000075039	41	38
28	7	8.51	10.31	6.38	0.000036466	43	41
28	8	9.06	10.86	6.61	0.000018751	44	43
28	8.5	9.23	11.04	6.67	0.000013603	44	44
29	2	0.11	2.52	0.98	0.008415081	26	21
29	3	0.96	3.16	2.18	0.001517353	29	26
29	4	3.32	5.31	3.75	0.000447166	33	31
29	5	5.58	7.43	4.98	0.000170211	38	34
29	6	7.17	8.97	5.73	0.000075418	40	37
29	7	8.13	9.92	6.15	0.000036740	42	40
29	8	8.67	10.47	6.37	0.000018956	43	42
29	8.5	8.84	10.64	6.44	0.000013783	43	43

Table A.3.1.4: The data of the dam in Example two used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
15	2	3.00	5.82	3.84	0.008295077	43	50
15	3	12.18	14.68	8.45	0.001464860	60	62
15	4	20.70	22.97	11.34	0.000418302	73	71
15	5	25.76	27.97	12.60	0.000152283	81	79
15	6	28.21	30.44	13.11	0.000063432	85	86
15	7	29.35	31.59	13.33	0.000028336	86	90
15	8	29.89	32.14	13.43	0.000012877	87	93
15	9	30.16	32.41	13.48	0.000005569	87	94
16	2	2.48	5.30	3.47	0.008316940	42	48
16	3	10.86	13.37	7.75	0.001474371	57	59
16	4	18.84	21.12	10.51	0.000423489	70	68
16	5	23.72	25.94	11.75	0.000155470	78	76
16	6	26.15	28.37	12.26	0.000065531	81	82
16	7	27.29	29.52	12.48	0.000029779	83	87
16	8	27.84	30.08	12.58	0.000013895	84	90
16	9	28.11	30.36	12.63	0.000006296	84	91
17	2	2.05	4.87	3.16	0.008335097	41	46
17	3	9.72	12.24	7.13	0.001482289	55	56
17	4	17.23	19.51	9.78	0.000427824	67	65

Table A.3.1.4.continued: The data of the dam in Example two used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
17	5	21.95	24.16	11.00	0.000158147	75	73
17	6	24.33	26.55	11.51	0.000067307	78	79
17	7	25.48	27.70	11.73	0.000031012	80	83
17	8	26.03	28.27	11.84	0.000014775	80	87
17	9	26.31	28.55	11.89	0.000006934	81	88
18	2	1.69	4.51	2.89	0.008350337	40	44
18	3	8.73	11.27	6.60	0.001488950	53	54
18	4	15.82	18.11	9.14	0.000431483	65	62
18	5	20.37	22.59	10.33	0.000160415	72	70
18	6	22.72	24.94	10.84	0.000068820	75	76
18	7	23.86	26.09	11.07	0.000032071	77	80
18	8	24.42	26.66	11.17	0.000015538	78	84
18	9	24.71	26.95	11.22	0.000007495	78	86
19	2	1.39	4.21	2.65	0.008363253	40	42
19	3	7.88	10.42	6.12	0.001494606	52	52
19	4	14.58	16.87	8.57	0.000434597	63	60
19	5	18.98	21.19	9.74	0.000162353	69	67
19	6	21.29	23.50	10.24	0.000070119	73	73
19	7	22.42	24.65	10.47	0.000032984	74	77
19	8	22.99	25.22	10.58	0.000016202	75	81
19	9	23.28	25.52	10.63	0.000007987	76	83

Table A.3.1.4.continued: The data of the dam in Example two used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
20	2	1.14	3.96	2.45	0.008374293	39	40
20	3	7.13	9.68	5.71	0.001499447	50	50
20	4	13.48	15.78	8.05	0.000437269	61	58
20	5	17.73	19.94	9.20	0.000164021	67	64
20	6	20.00	22.21	9.71	0.000071242	71	70
20	7	21.13	23.35	9.93	0.000033778	72	75
20	8	21.70	23.93	10.04	0.000016782	73	78
20	9	21.99	24.23	10.09	0.000008420	73	81
21	2	0.93	3.75	2.27	0.008383804	39	39
21	3	6.47	9.03	5.33	0.001503623	49	48
21	4	12.49	14.80	7.59	0.000439578	59	56
21	5	16.61	18.82	8.72	0.000165466	65	62
21	6	18.84	21.04	9.22	0.000072217	69	68
21	7	19.96	22.18	9.45	0.000034470	70	72
21	8	20.53	22.76	9.56	0.000017290	71	76
21	9	20.83	23.06	9.61	0.000008803	72	78
22	2	0.76	3.59	2.11	0.008392055	38	38
22	3	5.88	8.45	5.00	0.001507250	48	46
22	4	11.61	13.92	7.18	0.000441586	58	54
22	5	15.59	17.80	8.28	0.000166725	64	60
22	6	17.79	19.99	8.78	0.000073070	67	65

Table A.3.1.4.continued: The data of the dam in Example two used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
22	7	18.90	21.12	9.01	0.000035077	68	70
22	8	19.47	21.69	9.12	0.000017738	69	73
22	9	19.77	22.00	9.17	0.000009142	70	76
23	2	0.63	3.46	1.97	0.008399258	38	36
23	3	5.36	7.93	4.70	0.001510420	47	45
23	4	10.81	13.13	6.80	0.000443344	56	52
23	5	14.67	16.88	7.89	0.000167829	62	58
23	6	16.83	19.03	8.38	0.000073819	65	63
23	7	17.94	20.15	8.61	0.000035612	67	68
23	8	18.50	20.72	8.72	0.000018135	68	71
23	9	18.80	21.03	8.77	0.000009443	68	74
24	2	0.53	3.36	1.84	0.008405585	38	35
24	3	4.89	7.47	4.43	0.001513206	46	43
24	4	10.09	12.41	6.46	0.000444891	55	50
24	5	13.84	16.05	7.52	0.000168803	61	56
24	6	15.96	18.15	8.01	0.000074481	64	61
24	7	17.05	19.26	8.24	0.000036086	65	66
24	8	17.62	19.84	8.35	0.000018487	66	69
24	9	17.92	20.14	8.40	0.000009711	67	72
25	2	0.45	3.29	1.73	0.008411170	38	34
25	3	4.47	7.05	4.18	0.001515668	45	42

Table A.3.1.4.continued: The data of the dam in Example two used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
25	4	9.44	11.76	6.14	0.000446259	54	49
25	5	13.07	15.28	7.19	0.000169665	59	55
25	6	15.15	17.35	7.67	0.000075068	62	60
25	7	16.24	18.45	7.90	0.000036508	64	64
25	8	16.81	19.02	8.01	0.000018801	65	67
25	9	17.11	19.33	8.07	0.000009952	65	70
26	2	0.39	3.24	1.63	0.008416127	37	33
26	3	4.09	6.68	3.96	0.001517853	45	41
26	4	8.84	11.17	5.85	0.000447475	53	47
26	5	12.37	14.58	6.88	0.000170432	58	53
26	6	14.41	16.61	7.36	0.000075591	61	58
26	7	15.49	17.69	7.59	0.000036884	63	62
26	8	16.06	18.27	7.70	0.000019082	64	65
26	9	16.36	18.58	7.75	0.000010167	64	68
27	2	0.35	3.21	1.54	0.008420544	37	32
27	3	3.74	6.34	3.75	0.001519803	44	40
27	4	8.29	10.63	5.59	0.000448561	52	46
27	5	11.72	13.93	6.59	0.000171118	57	52
27	6	13.73	15.92	7.07	0.000076060	60	56
27	7	14.80	17.00	7.30	0.000037222	62	60
27	8	15.36	17.57	7.41	0.000019334	62	64

Table A.3.1.4.continued: The data of the dam in Example two used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
27	9	15.66	17.88	7.46	0.000010361	63	66
28	2	0.32	3.18	1.45	0.008424499	37	31
28	3	3.43	6.03	3.57	0.001521549	43	39
28	4	7.79	10.13	5.34	0.000449534	51	45
28	5	11.12	13.33	6.33	0.000017133	56	34
28	6	13.10	15.29	6.80	0.000076489	59	55
28	7	14.16	16.36	7.03	0.000037525	60	59
28	8	14.72	16.93	7.14	0.000019561	61	62
28	9	15.02	17.23	7.20	0.000010536	62	65
29	2	0.29	3.16	1.38	0.008428053	37	30
29	3	3.15	5.75	3.39	0.001523119	43	38
29	4	7.33	9.67	5.11	0.000450409	50	44
29	5	10.57	12.78	6.09	0.000172287	55	49
29	6	12.51	14.70	6.56	0.000076860	58	53
29	7	13.56	15.76	6.78	0.000037799	59	57
29	8	14.12	16.32	6.89	0.000019767	60	61
29	9	14.42	16.63	6.95	0.000010695	61	63

For the dam in Example three (Cofcof, 2011) and Gezende dam,

Table A.3.1.5: The system parameters of the dam in Example three that are already known

Q_{min} (m^3/s)	25
Q_{max} (m^3/s)	40
H_{resmax} (m)	350
H_{resmin} (m)	335
L_t (m)	4000
D_t (m)	4

Table A.3.1.6: The system parameters of Gezende dam that are already known

Q_{min} (m^3/s)	29.25
Q_{max} (m^3/s)	117
H_{resmax} (m)	333
H_{resmin} (m)	310
L_t (m)	8629
D_t (m)	5.6

Table A.3.1.7: The data of the dam in Example three used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
10	2	14.99	21.25	13.99	0.007637059	50	46
10	3	19.22	25.54	15.96	0.001176091	57	55
10	4	20.02	26.39	16.31	0.000258770	59	61
11	2	12.85	19.09	12.57	0.007706141	46	42
11	3	16.92	23.20	14.50	0.001205339	53	51
11	4	17.71	24.05	14.85	0.000274076	54	57
12	2	11.11	17.32	11.40	0.007759016	42	40
12	3	15.02	21.26	13.28	0.001227918	49	48
12	4	15.80	22.10	13.63	0.000286051	50	54
13	2	9.67	15.86	10.42	0.007800365	39	37
13	3	13.42	19.63	12.55	0.001245689	46	45
13	4	14.19	20.46	12.60	0.000295569	47	51
14	2	8.46	14.63	9.59	0.007833298	37	35
14	3	12.06	18.23	11.37	0.001259913	43	43
14	4	12.82	19.06	11.72	0.000303246	44	48
15	2	7.44	13.58	8.87	0.007859947	35	34
15	3	10.89	17.03	10.60	0.001271469	41	41
15	4	11.63	17.85	10.95	0.000309519	42	46
16	2	6.58	12.70	8.25	0.007881811	33	32
16	3	9.88	15.99	9.94	0.001280980	39	39
16	4	10.61	16.79	10.29	0.000314706	40	44

Table A.3.1.7.continued: The data of the dam in Example three used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
18	2	5.20	11.29	7.24	0.007915207	30	29
18	3	8.22	14.26	8.83	0.001295559	35	36
18	4	8.91	15.03	9.17	0.000322700	37	40
20	2	4.17	10.25	6.44	0.007939163	28	27
20	3	6.93	12.90	7.95	0.001306056	33	33
20	4	7.58	13.64	8.29	0.000328486	34	37
21	2	3.76	9.84	6.11	0.007948674	27	26
21	3	6.38	12.33	7.57	0.001310232	32	32
21	4	7.02	13.05	7.91	0.000330795	33	36
22	2	3.40	9.50	5.81	0.007956925	26	25
22	3	5.90	11.81	7.23	0.001313859	31	31
22	4	6.51	12.51	7.56	0.000332804	32	35
23	2	3.08	9.23	5.54	0.007964128	25	24
23	3	5.46	11.34	6.92	0.001317029	30	30
23	4	6.05	12.03	7.25	0.000334562	31	33
24	2	2.81	9.02	5.29	0.007970455	25	24
24	3	5.06	10.92	6.64	0.001319815	29	29
24	4	5.64	11.59	6.96	0.000336109	30	32

Table A.3.1.7.continued: The data of the dam in Example three used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
25	2	2.57	8.86	5.07	0.007976040	24	23
25	3	4.70	10.54	6.38	0.001322277	28	28
25	4	5.26	11.19	6.70	0.000337477	29	31
26	2	2.36	8.77	4.87	0.007980997	24	22
26	3	4.38	10.20	6.14	0.001324462	28	27
26	4	4.92	10.82	6.45	0.000338693	29	30
27	2	2.17	8.73	4.69	0.007985415	23	21
27	3	4.09	9.89	5.92	0.001326412	27	26
27	4	4.61	10.49	6.23	0.000339778	28	30
28	2	2.01	8.72	4.52	0.007989369	23	21
28	3	3.82	9.62	5.71	0.001328158	26	25
28	4	4.32	10.18	6.02	0.000340751	27	29
29	2	1.86	8.71	4.37	0.007992923	22	20
29	3	3.57	9.37	5.52	0.001329727	26	25
29	4	4.06	9.90	5.83	0.000341627	27	28

Table A.3.1.8: The data of Gezende dam used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
9	2	37.52	57.17	18.61	0.007810068	114	95
10	2	30.56	50.24	16.47	0.007902645	97	88
11	2	25.12	44.81	14.73	0.007971727	84	82
11	3	46.72	65.34	17.39	0.001323377	134	100
12	2	20.81	40.51	13.30	0.008024603	74	77
12	3	40.98	59.50	15.89	0.001345956	121	94
12	4	47.04	65.80	16.40	0.000352447	135	107
13	2	17.36	37.06	12.10	0.008065952	65	72
13	3	36.20	54.61	14.62	0.001363727	109	88
13	4	42.09	60.74	15.13	0.000361966	123	101
13	5	43.82	62.62	15.27	0.000116682	128	110
14	2	14.57	34.28	11.08	0.008098885	59	69
14	3	32.16	50.48	13.53	0.001377952	99	84
14	4	37.88	56.43	14.05	0.000369643	113	96
14	5	39.59	58.29	14.18	0.000121328	117	104
15	2	12.31	32.05	10.20	0.008125534	53	65
15	3	28.71	46.94	12.59	0.001389507	91	80
15	4	34.27	52.71	13.11	0.000375916	104	91
15	5	35.94	54.56	13.24	0.000125156	109	100

Table A.3.1.8.continued: The data of Gezende dam used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
16	2	10.47	30.28	9.44	0.008147397	49	62
16	3	25.75	43.88	11.77	0.001399018	84	76
16	4	31.13	49.47	12.28	0.000381103	97	87
16	5	32.78	51.30	12.42	0.000128343	101	95
17	2	8.98	28.91	8.78	0.008165553	45	59
17	3	23.18	41.22	11.05	0.001406937	77	72
17	4	28.39	46.63	11.56	0.000385438	90	83
17	5	30.00	48.43	11.69	0.000131020	94	91
18	2	7.77	27.90	8.19	0.008180793	43	57
18	3	20.94	38.90	10.41	0.001413598	72	69
18	4	25.97	44.12	10.91	0.000389097	84	80
18	5	27.56	45.89	11.05	0.000133288	88	88
19	2	6.78	27.19	7.67	0.008193709	41	54
19	3	18.98	36.86	9.83	0.001419253	67	67
19	4	23.84	41.89	10.33	0.000392211	79	76
19	5	25.38	43.63	10.47	0.000135226	83	84
20	2	5.98	26.74	7.20	0.008204750	39	52
20	3	17.26	35.06	9.31	0.001424095	63	64
20	4	21.94	39.90	9.81	0.000394883	74	74
20	5	23.45	41.60	9.95	0.000136894	78	81

Table A.3.1.8.continued: The data of Gezende dam used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
21	2	5.32	26.47	6.79	0.008214260	38	50
21	3	15.73	33.48	8.85	0.001428271	59	62
21	4	20.24	38.11	9.34	0.000397192	70	71
21	5	21.71	39.78	9.48	0.000138339	74	78
22	2	4.78	26.31	6.41	0.008222511	37	49
22	3	14.38	32.08	8.42	0.001431898	56	60
22	4	18.72	36.50	8.92	0.000399200	66	69
22	5	20.15	38.13	9.05	0.000139598	70	76
23	2	4.32	26.22	6.07	0.008229715	37	47
23	3	13.18	30.84	8.04	0.001435067	53	58
23	4	17.35	35.05	8.53	0.000400958	63	66
23	5	18.74	36.64	8.66	0.000140702	66	73
24	2	3.94	26.16	5.76	0.008236041	36	46
24	3	12.11	29.76	7.69	0.001437853	50	56
24	4	16.12	33.73	8.17	0.000402505	60	64
24	5	17.47	35.28	8.31	0.000141676	63	71
25	2	3.61	26.13	5.48	0.008241627	36	44
25	3	11.16	28.81	7.36	0.001440315	48	54

Table A.3.1.8.continued: The data of Gezende dam used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	$H_{main\ tank}$ (m)	$H_{main\ tank}$ obt.
25	4	15.00	32.54	7.84	0.000403874	57	62
25	5	16.30	34.05	7.98	0.000142538	60	69
26	2	3.33	26.11	5.22	0.008246583	35	43
26	3	10.30	28.00	7.06	0.001442501	46	53
26	4	13.98	31.46	7.54	0.000405090	55	61
26	5	15.25	32.92	7.68	0.000143305	58	67
27	2	3.08	26.09	4.99	0.008251001	35	42
27	3	9.54	27.32	6.78	0.001444450	44	51
27	4	13.05	30.48	7.26	0.000406175	52	59
27	5	14.28	31.88	7.39	0.000143991	55	65
28	2	2.86	26.04	4.77	0.008254955	35	40
28	3	8.85	26.77	6.53	0.001446196	43	50
28	4	12.21	29.59	7.00	0.000407148	50	57
28	5	13.40	30.94	7.13	0.000144606	53	63
29	2	2.66	25.95	4.57	0.008258509	34	39
29	3	8.23	26.37	6.29	0.001447766	42	48
29	4	11.44	28.80	6.76	0.000408023	48	56
29	5	12.58	30.07	6.89	0.000145160	51	62

A.3.2 Tank Height Values corresponding to Shafted Surge Tank Equations

The Data corresponding to four dams are given respectively.

For the dams in Example one and Example two (Cofcof, 2011),

Table A.3.2.1: The system parameters of the dam in Example one that are already known

Q_{min} (m^3/s)	150
Q_{max} (m^3/s)	250
c_t	0.000039339
H_{resmax} (m)	450
H_{resmin} (m)	425
L_t (m)	700
D_t (m)	8.5

Table A.3.2.2: The system parameters of the dam in Example two that are already known

Q_{min} (m^3/s)	100
Q_{max} (m^3/s)	240
H_{resmax} (m)	445
H_{resmin} (m)	410
L_t (m)	2000
D_t (m)	9

Table A.3.2.3: The data of the dam in Example one used in the calculations

							H_{tank} obtained from developed eqns.	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
9	2	3.83	6.15	4.97	0.007966640	52	67	58
10	2	2.89	5.22	4.19	0.008059217	51	66	57
10	3	12.00	14.08	10.36	0.001363717	62	70	74
12	2	1.65	3.99	3.13	0.008181175	50	65	56
12	3	8.56	10.66	7.93	0.001415544	58	67	68
13	2	1.24	3.58	2.75	0.008222523	49	65	57
13	3	7.33	9.45	7.05	0.001433314	57	65	66
13	4	13.88	15.79	10.80	0.000401109	64	71	79
15	2	0.69	3.04	2.20	0.008282106	49	67	58
15	3	5.49	7.63	5.71	0.001459095	54	63	63
15	4	11.05	12.98	8.97	0.000415059	61	68	74
15	5	15.78	16.91	10.94	0.000150208	67	72	81
16	2	0.52	2.87	2.00	0.008303969	48	67	59
16	3	4.79	6.94	5.19	0.001468606	53	62	62
16	4	9.95	11.88	8.25	0.000420246	60	67	72
16	5	13.79	15.62	10.14	0.000153394	64	71	79
16	6	16.43	17.80	11.09	0.000064089	67	74	82
16	7	17.39	18.93	11.54	0.000028720	69	76	82
18	2	0.33	2.69	1.67	0.008337365	48	69	61

Table A.3.2.3.continued: The data of the dam in Example one used in the calculations

							H_{tank} obtained from developed eqns.	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
18	3	3.69	5.85	4.37	0.001483185	52	61	61
18	4	8.16	10.11	7.07	0.000428240	58	64	69
18	5	11.66	13.49	8.83	0.000158340	62	69	75
18	6	13.74	15.56	9.75	0.000067379	64	72	78
18	7	14.85	16.67	10.20	0.000031012	66	74	79
18	8	15.41	17.25	10.42	0.000014727	66	75	78
18	8.5	15.58	17.42	10.48	0.000010113	66	75	77
19	2	0.28	2.65	1.55	0.008350281	48	69	62
19	3	3.25	5.42	4.03	0.001488841	52	60	61
19	4	7.44	9.39	6.58	0.000431354	57	63	68
19	5	10.78	12.61	8.28	0.000160278	61	68	74
19	6	12.81	14.62	9.18	0.000068678	63	71	77
19	7	13.90	15.72	9.63	0.000031925	64	73	78
19	8	14.47	16.30	9.86	0.000015391	65	74	77
19	8.5	14.64	16.48	9.92	0.000010684	65	74	76
21	2	0.22	2.60	1.35	0.008370832	48	68	64
21	3	2.53	4.71	3.48	0.001497858	51	59	60
21	4	6.23	8.19	5.76	0.000436335	55	62	66
21	5	9.29	11.13	7.35	0.000163390	59	66	72
21	6	11.23	13.03	8.22	0.000070776	61	69	75

Table A.3.2.3.continued: The data of the dam in Example one used in the calculations

							H_{tank} obtained from developed eqns.	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	Htank (m)	Equation (5.9)	Equation (5.10)
21	7	12.29	14.11	8.67	0.000033411	63	71	75
21	8	12.86	14.68	8.89	0.000016479	63	73	75
21	8.5	13.03	14.86	8.96	0.000011624	63	73	75
23	2	0.18	2.57	1.20	0.008386287	48	68	65
23	3	1.98	4.17	3.05	0.001504655	50	59	60
23	4	5.26	7.24	5.11	0.000440101	54	60	65
23	5	8.09	9.93	6.59	0.000165754	57	64	70
23	6	9.93	11.74	7.43	0.000072378	60	67	73
23	7	10.97	12.78	7.87	0.000034554	61	70	74
23	8	11.53	13.35	8.09	0.000017324	62	71	73
23	8.5	11.70	13.53	8.16	0.000012357	62	72	73
24	2	0.16	2.56	1.15	0.008392613	48	68	66
24	3	1.76	3.94	2.87	0.001507441	50	59	60
24	4	4.86	6.84	4.83	0.000441648	54	60	64
24	5	7.57	9.42	6.26	0.000166727	57	63	69
24	6	9.37	11.17	7.09	0.000073039	59	66	72
24	7	10.39	12.20	7.52	0.000035027	60	69	73
24	8	10.95	12.77	7.75	0.000017676	61	70	73
24	8.5	11.13	12.94	7.82	0.000012664	61	71	72

Table A.3.2.3.continued: The data of the dam in Example one used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	Htank (m)	H_{tank} obtained from developed eqns	
							Equation (5.9)	Equation (5.10)
26	2	0.14	2.54	1.06	0.008403155	48	67	67
26	3	1.38	3.57	2.55	0.001512088	49	59	60
26	4	4.15	6.14	4.34	0.000444233	53	59	64
26	5	6.67	8.52	5.68	0.000168357	56	62	68
26	6	8.38	10.18	6.48	0.000074150	58	65	70
26	7	9.38	11.18	6.91	0.000035825	59	67	71
26	8	9.93	11.74	7.13	0.000018271	60	69	71
26	8.5	10.10	11.92	7.20	0.000013183	60	69	71
28	2	0.12	2.52	1.00	0.008411527	48	67	68
28	3	1.08	3.28	2.30	0.001515784	49	59	61
28	4	3.57	5.57	3.93	0.000446291	52	58	63
28	5	5.92	7.77	5.19	0.000169657	55	60	67
28	6	7.55	9.34	5.96	0.000075039	57	63	69
28	7	8.51	10.31	6.38	0.000036466	58	66	70
28	8	9.06	10.86	6.61	0.000018751	59	68	70
28	8.5	9.23	11.04	6.67	0.000013603	59	68	70
29	2	0.11	2.52	0.98	0.008415081	48	67	69
29	3	0.96	3.16	2.18	0.001517353	49	59	61
29	4	3.32	5.31	3.75	0.000447166	52	58	63
29	5	5.58	7.43	4.98	0.000170211	54	60	66
29	6	7.17	8.97	5.73	0.000075418	56	63	69
29	7	8.13	9.92	6.15	0.000036740	58	65	70
29	8	8.67	10.47	6.37	0.000018956	58	67	70
29	8.5	8.84	10.64	6.44	0.000013783	58	68	70

Table A.3.2.4: The data of the dam in Example two used in the calculations

							H_{tank} obtained from developed eqns.	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
15	2	3.00	5.82	3.84	0.008295077	79	78	72
15	3	12.18	14.68	8.45	0.001464860	90	82	85
15	4	20.70	22.97	11.34	0.000418302	100	90	97
15	5	25.76	27.97	12.60	0.000152283	106	96	103
15	6	28.21	30.44	13.11	0.000063432	109	101	104
15	7	29.35	31.59	13.33	0.000028336	111	103	104
15	8	29.89	32.14	13.43	0.000012877	111	103	102
15	9	30.16	32.41	13.48	0.000005569	112	101	98
16	2	2.48	5.30	3.47	0.008316940	78	78	72
16	3	10.86	13.37	7.75	0.001474371	89	81	83
16	4	18.84	21.12	10.51	0.000423489	98	88	94
16	5	23.72	25.94	11.75	0.000155470	104	94	100
16	6	26.15	28.37	12.26	0.000065531	107	99	102
16	7	27.29	29.52	12.48	0.000029779	108	102	102
16	8	27.84	30.08	12.58	0.000013895	109	103	100
16	9	28.11	30.36	12.63	0.000006296	109	101	97
17	2	2.05	4.87	3.16	0.008335097	78	78	72
17	3	9.72	12.24	7.13	0.001482289	87	79	81
17	4	17.23	19.51	9.78	0.000427824	96	86	92

Table A.3.2.4.continued: The data of the dam in Example two used in the calculations

							H_{tank} obtained from developed eqns.	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
17	5	21.95	24.16	11.00	0.000158147	102	92	98
17	6	24.33	26.55	11.51	0.000067307	105	97	100
17	7	25.48	27.70	11.73	0.000031012	106	100	100
17	8	26.03	28.27	11.84	0.000014775	107	101	98
17	9	26.31	28.55	11.89	0.000006934	107	100	96
18	2	1.69	4.51	2.89	0.008350337	78	78	73
18	3	8.73	11.27	6.60	0.001488950	86	78	80
18	4	15.82	18.11	9.14	0.000431483	94	85	91
18	5	20.37	22.59	10.33	0.000160415	100	91	96
18	6	22.72	24.94	10.84	0.000068820	103	95	98
18	7	23.86	26.09	11.07	0.000032071	104	99	98
18	8	24.42	26.66	11.17	0.000015538	105	100	97
18	9	24.71	26.95	11.22	0.000007495	105	100	95
19	2	1.39	4.21	2.65	0.008363253	77	78	73
19	3	7.88	10.42	6.12	0.001494606	85	77	79
19	4	14.58	16.87	8.57	0.000434597	93	83	89
19	5	18.98	21.19	9.74	0.000162353	98	89	95
19	6	21.29	23.50	10.24	0.000070119	101	94	97
19	7	22.42	24.65	10.47	0.000032984	102	97	97
19	8	22.99	25.22	10.58	0.000016202	103	99	96
19	9	23.28	25.52	10.63	0.000007987	103	99	94

Table A.3.2.4.continued: The data of the dam in Example two used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	H_{tank} obtained from developed eqns. Equation (5.9)	Equation (5.10)
20	2	1.14	3.96	2.45	0.008374293	77	79	74
20	3	7.13	9.68	5.71	0.001499447	84	76	78
20	4	13.48	15.78	8.05	0.000437269	92	82	88
20	5	17.73	19.94	9.20	0.000164021	97	88	93
20	6	20.00	22.21	9.71	0.000071242	100	92	95
20	7	21.13	23.35	9.93	0.000033778	101	96	95
20	8	21.70	23.93	10.04	0.000016782	102	98	94
20	9	21.99	24.23	10.09	0.000008420	102	98	93
21	2	0.93	3.75	2.27	0.008383804	77	79	75
21	3	6.47	9.03	5.33	0.001503623	83	75	78
21	4	12.49	14.80	7.59	0.000439578	90	81	86
21	5	16.61	18.82	8.72	0.000165466	95	86	92
21	6	18.84	21.04	9.22	0.000072217	98	91	94
21	7	19.96	22.18	9.45	0.000034470	99	95	94
21	8	20.53	22.76	9.56	0.000017290	100	97	93
21	9	20.83	23.06	9.61	0.000008803	100	97	92
22	2	0.76	3.59	2.11	0.008392055	76	80	76
22	3	5.88	8.45	5.00	0.001507250	83	75	77
22	4	11.61	13.92	7.18	0.000441586	89	80	85
22	5	15.59	17.80	8.28	0.000166725	94	85	90
22	6	17.79	19.99	8.78	0.000073070	97	90	93

Table A.3.2.4.continued: The data of the dam in Example two used in the calculations

							H_{tank} obtained from developed eqns.	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
22	7	18.90	21.12	9.01	0.000035077	98	93	93
22	8	19.47	21.69	9.12	0.000017738	99	96	92
22	9	19.77	22.00	9.17	0.000009142	99	97	91
23	2	0.63	3.46	1.97	0.008399258	76	81	77
23	3	5.36	7.93	4.70	0.001510420	82	74	77
23	4	10.81	13.13	6.80	0.000443344	88	79	84
23	5	14.67	16.88	7.89	0.000167829	93	84	89
23	6	16.83	19.03	8.38	0.000073819	96	89	92
23	7	17.94	20.15	8.61	0.000035612	97	92	92
23	8	18.50	20.72	8.72	0.000018135	98	95	91
23	9	18.80	21.03	8.77	0.000009443	98	96	90
24	2	0.53	3.36	1.84	0.008405585	76	81	78
24	3	4.89	7.47	4.43	0.001513206	81	73	76
24	4	10.09	12.41	6.46	0.000444891	88	78	84
24	5	13.84	16.05	7.52	0.000168803	92	83	88
24	6	15.96	18.15	8.01	0.000074481	95	88	91
24	7	17.05	19.26	8.24	0.000036086	96	91	91
24	8	17.62	19.84	8.35	0.000018487	97	94	90
24	9	17.92	20.14	8.40	0.000009711	97	95	89
25	2	0.45	3.29	1.73	0.008411170	76	82	79
25	3	4.47	7.05	4.18	0.001515668	81	73	76

Table A.3.2.4.continued: The data of the dam in Example two used in the calculations

							H_{tank} obtained from developed eqns.	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
25	4	9.44	11.76	6.14	0.000446259	87	77	83
25	5	13.07	15.28	7.19	0.000169665	91	82	87
25	6	15.15	17.35	7.67	0.000075068	94	86	90
25	7	16.24	18.45	7.90	0.000036508	95	90	90
25	8	16.81	19.02	8.01	0.000018801	96	93	90
25	9	17.11	19.33	8.07	0.000009952	96	94	88
26	2	0.39	3.24	1.63	0.008416127	76	82	80
26	3	4.09	6.68	3.96	0.001517853	80	73	76
26	4	8.84	11.17	5.85	0.000447475	86	76	82
26	5	12.37	14.58	6.88	0.000170432	90	81	87
26	6	14.41	16.61	7.36	0.000075591	93	85	89
26	7	15.49	17.69	7.59	0.000036884	94	89	89
26	8	16.06	18.27	7.70	0.000019082	95	92	89
26	9	16.36	18.58	7.75	0.000010167	95	93	88
27	2	0.35	3.21	1.54	0.008420544	76	82	81
27	3	3.74	6.34	3.75	0.001519803	80	72	76
27	4	8.29	10.63	5.59	0.000448561	85	75	82
27	5	11.72	13.93	6.59	0.000171118	90	80	86
27	6	13.73	15.92	7.07	0.000076060	92	84	88
27	7	14.80	17.00	7.30	0.000037222	93	88	89
27	8	15.36	17.57	7.41	0.000019334	94	91	88

Table A.3.2.4.continued: The data of the dam in Example two used in the calculations

							H_{tank} obtained from developed eqns.	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
27	9	15.66	17.88	7.46	0.000010361	94	92	87
28	2	0.32	3.18	1.45	0.008424499	76	82	82
28	3	3.43	6.03	3.57	0.001521549	80	72	76
28	4	7.79	10.13	5.34	0.000449534	85	75	81
28	5	11.12	13.33	6.33	0.000017133	89	48	68
28	6	13.10	15.29	6.80	0.000076489	91	84	87
28	7	14.16	16.36	7.03	0.000037525	92	87	88
28	8	14.72	16.93	7.14	0.000019561	93	90	88
28	9	15.02	17.23	7.20	0.000010536	94	91	87
29	2	0.29	3.16	1.38	0.008428053	76	82	82
29	3	3.15	5.75	3.39	0.001523119	79	72	76
29	4	7.33	9.67	5.11	0.000450409	84	74	81
29	5	10.57	12.78	6.09	0.000172287	88	78	85
29	6	12.51	14.70	6.56	0.000076860	91	83	87
29	7	13.56	15.76	6.78	0.000037799	92	86	87
29	8	14.12	16.32	6.89	0.000019767	92	89	87
29	9	14.42	16.63	6.95	0.000010695	93	91	86

For the dam in Example three (Cofcof, 2011) and Gezende dam,

Table A.3.2.5: The system parameters of the dam in Example three that are already known

Q_{min} (m^3/s)	25
Q_{max} (m^3/s)	40
H_{resmax} (m)	350
H_{resmin} (m)	335
L_t (m)	4000
D_t (m)	4

Table A.3.2.6: The system parameters of Gezende dam that are already known

Q_{min} (m^3/s)	29.25
Q_{max} (m^3/s)	117
H_{resmax} (m)	333
H_{resmin} (m)	310
L_t (m)	8629
D_t (m)	5.6

Table A.3.2.7.: The data of the dam in Example three used in the calculations

							H_{tank} obtained from developed eqns.	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
10	2	14.99	21.25	13.99	0.007637059	56	45	55
10	3	19.22	25.54	15.96	0.001176091	61	51	60
10	4	20.02	26.39	16.31	0.000258770	62	53	59
11	2	12.85	19.09	12.57	0.007706141	53	43	52
11	3	16.92	23.20	14.50	0.001205339	58	49	57
11	4	17.71	24.05	14.85	0.000274076	59	52	56
12	2	11.11	17.32	11.40	0.007759016	51	42	50
12	3	15.02	21.26	13.28	0.001227918	56	48	54
12	4	15.80	22.10	13.63	0.000286051	57	50	54
13	2	9.67	15.86	10.42	0.007800365	50	41	47
13	3	13.42	19.63	12.55	0.001245689	54	46	52
13	4	14.19	20.46	12.60	0.000295569	55	49	52
14	2	8.46	14.63	9.59	0.007833298	48	39	46
14	3	12.06	18.23	11.37	0.001259913	52	45	50
14	4	12.82	19.06	11.72	0.000303246	53	48	50
15	2	7.44	13.58	8.87	0.007859947	47	39	44
15	3	10.89	17.03	10.60	0.001271469	51	44	49
15	4	11.63	17.85	10.95	0.000309519	52	47	48
16	2	6.58	12.70	8.25	0.007881811	46	38	43
16	3	9.88	15.99	9.94	0.001280980	50	43	47
16	4	10.61	16.79	10.29	0.000314706	51	47	47

Table A.3.2.7.continued: The data of the dam in Example three used in the calculations

							H_{tank} obtained from developed eqns.	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
18	2	5.20	11.29	7.24	0.007915207	44	36	41
18	3	8.22	14.26	8.83	0.001295559	48	41	45
18	4	8.91	15.03	9.17	0.000322700	49	44	45
20	2	4.17	10.25	6.44	0.007939163	43	35	39
20	3	6.93	12.90	7.95	0.001306056	46	40	43
20	4	7.58	13.64	8.29	0.000328486	47	43	43
21	2	3.76	9.84	6.11	0.007948674	43	35	38
21	3	6.38	12.33	7.57	0.001310232	46	39	42
21	4	7.02	13.05	7.91	0.000330795	46	42	42
22	2	3.40	9.50	5.81	0.007956925	42	35	38
22	3	5.90	11.81	7.23	0.001313859	45	38	41
22	4	6.51	12.51	7.56	0.000332804	46	41	41
23	2	3.08	9.23	5.54	0.007964128	42	34	37
23	3	5.46	11.34	6.92	0.001317029	45	38	41
23	4	6.05	12.03	7.25	0.000334562	45	41	41
24	2	2.81	9.02	5.29	0.007970455	41	34	37
24	3	5.06	10.92	6.64	0.001319815	44	37	40
24	4	5.64	11.59	6.96	0.000336109	45	40	40

Table A.3.2.7.continued: The data of the dam in Example three used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	H_{tank} obtained from developed eqns.	
							Equation (5.9)	Equation (5.10)
25	2	2.57	8.86	5.07	0.007976040	41	34	37
25	3	4.70	10.54	6.38	0.001322277	44	37	40
25	4	5.26	11.19	6.70	0.000337477	44	40	40
26	2	2.36	8.77	4.87	0.007980997	41	33	37
26	3	4.38	10.20	6.14	0.001324462	43	37	39
26	4	4.92	10.82	6.45	0.000338693	44	39	39
27	2	2.17	8.73	4.69	0.007985415	41	33	36
27	3	4.09	9.89	5.92	0.001326412	43	36	39
27	4	4.61	10.49	6.23	0.000339778	44	39	39
28	2	2.01	8.72	4.52	0.007989369	40	33	36
28	3	3.82	9.62	5.71	0.001328158	43	36	38
28	4	4.32	10.18	6.02	0.000340751	43	39	38
29	2	1.86	8.71	4.37	0.007992923	40	33	36
29	3	3.57	9.37	5.52	0.001329727	42	36	38
29	4	4.06	9.90	5.83	0.000341627	43	38	38

Table A.3.2.8: The data of Gezende dam used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	H_{tank} obtained from developed eqns. Equation (5.9)	H_{tank} obtained from developed eqns. Equation (5.10)
9	2	37.52	57.17	18.61	0.007810068	126	112	136
10	2	30.56	50.24	16.47	0.007902645	117	106	121
11	2	25.12	44.81	14.73	0.007971727	111	101	109
11	3	46.72	65.34	17.39	0.001323377	137	123	157
12	2	20.81	40.51	13.30	0.008024603	106	97	99
12	3	40.98	59.50	15.89	0.001345956	130	118	145
12	4	47.04	65.80	16.40	0.000352447	137	130	156
13	2	17.36	37.06	12.10	0.008065952	102	93	91
13	3	36.20	54.61	14.62	0.001363727	124	113	135
13	4	42.09	60.74	15.13	0.000361966	131	125	147
13	5	43.82	62.62	15.27	0.000116682	133	132	147
14	2	14.57	34.28	11.08	0.008098885	98	90	84
14	3	32.16	50.48	13.53	0.001377952	119	109	126
14	4	37.88	56.43	14.05	0.000369643	126	121	138
14	5	39.59	58.29	14.18	0.000121328	128	128	139
15	2	12.31	32.05	10.20	0.008125534	96	88	79
15	3	28.71	46.94	12.59	0.001389507	115	105	118
15	4	34.27	52.71	13.11	0.000375916	122	117	130
15	5	35.94	54.56	13.24	0.000125156	124	124	132

Table A.3.2.8.continued: The data of Gezende dam used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	H_{tank} obtained from developed eqns.	
							Equation (5.9)	Equation (5.10)
16	2	10.47	30.28	9.44	0.008147397	93	85	74
16	3	25.75	43.88	11.77	0.001399018	112	102	111
16	4	31.13	49.47	12.28	0.000381103	118	114	124
16	5	32.78	51.30	12.42	0.000128343	120	121	125
17	2	8.98	28.91	8.78	0.008165553	92	84	71
17	3	23.18	41.22	11.05	0.001406937	109	99	105
17	4	28.39	46.63	11.56	0.000385438	115	111	117
17	5	30.00	48.43	11.69	0.000131020	117	118	119
18	2	7.77	27.90	8.19	0.008180793	90	82	68
18	3	20.94	38.90	10.41	0.001413598	106	96	100
18	4	25.97	44.12	10.91	0.000389097	112	108	112
18	5	27.56	45.89	11.05	0.000133288	114	115	114
19	2	6.78	27.19	7.67	0.008193709	89	81	67
19	3	18.98	36.86	9.83	0.001419253	104	94	95
19	4	23.84	41.89	10.33	0.000392211	109	105	107
19	5	25.38	43.63	10.47	0.000135226	111	112	109
20	2	5.98	26.74	7.20	0.008204750	88	80	65
20	3	17.26	35.06	9.31	0.001424095	101	92	91
20	4	21.94	39.90	9.81	0.000394883	107	103	102
20	5	23.45	41.60	9.95	0.000136894	109	110	105

Table A.3.2.8.continued: The data of Gezende dam used in the calculations

							H_{tank} obtained from developed eqns.	
D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	Equation (5.9)	Equation (5.10)
21	2	5.32	26.47	6.79	0.008214260	87	79	65
21	3	15.73	33.48	8.85	0.001428271	100	90	87
21	4	20.24	38.11	9.34	0.000397192	105	100	98
21	5	21.71	39.78	9.48	0.000138339	107	107	101
22	2	4.78	26.31	6.41	0.008222511	86	79	64
22	3	14.38	32.08	8.42	0.001431898	98	88	84
22	4	18.72	36.50	8.92	0.000399200	103	98	95
22	5	20.15	38.13	9.05	0.000139598	105	105	97
23	2	4.32	26.22	6.07	0.008229715	86	78	64
23	3	13.18	30.84	8.04	0.001435067	97	86	81
23	4	17.35	35.05	8.53	0.000400958	102	96	91
23	5	18.74	36.64	8.66	0.000140702	103	103	94
24	2	3.94	26.16	5.76	0.008236041	85	77	64
24	3	12.11	29.76	7.69	0.001437853	95	85	78
24	4	16.12	33.73	8.17	0.000402505	100	94	88
24	5	17.47	35.28	8.31	0.000141676	102	101	91
25	2	3.61	26.13	5.48	0.008241627	85	77	64
25	3	11.16	28.81	7.36	0.001440315	94	83	76

Table A.3.2.8.continued: The data of Gezende dam used in the calculations

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	C_{shaft}	H_{tank} (m)	H_{tank} obtained from developed eqns.	
							Equation (5.9)	Equation (5.10)
25	4	15.00	32.54	7.84	0.000403874	99	93	85
25	5	16.30	34.05	7.98	0.000142538	100	99	88
26	2	3.33	26.11	5.22	0.008246583	85	77	64
26	3	10.30	28.00	7.06	0.001442501	93	82	73
26	4	13.98	31.46	7.54	0.000405090	98	91	83
26	5	15.25	32.92	7.68	0.000143305	99	98	85
27	2	3.08	26.09	4.99	0.008251001	84	76	65
27	3	9.54	27.32	6.78	0.001444450	92	81	72
27	4	13.05	30.48	7.26	0.000406175	96	90	80
27	5	14.28	31.88	7.39	0.000143991	98	96	83
28	2	2.86	26.04	4.77	0.008254955	84	76	65
28	3	8.85	26.77	6.53	0.001446196	91	80	70
28	4	12.21	29.59	7.00	0.000407148	95	88	78
28	5	13.40	30.94	7.13	0.000144606	97	95	81
29	2	2.66	25.95	4.57	0.008258509	84	75	65
29	3	8.23	26.37	6.29	0.001447766	91	79	69
29	4	11.44	28.80	6.76	0.000408023	94	87	76
29	5	12.58	30.07	6.89	0.000145160	96	93	78

APPENDIX B

VALUES THAT ARE USED IN THE INVESTIGATION OF THE COST FUNCTION

B.1 Values corresponding to Simple Surge Tank

The Data corresponding to Figures (6.1) and (6.2) are given in Table (B.1.1).

Table B.1.1: The Data corresponding to Figures (6.1) and (6.2)

D_{tank} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	H_{tank} (m)	COST (TL)
17	26.32	28.85	11.94	107.09	1.640.053
18	24.72	27.27	11.28	105.17	1.715.001
19	23.29	25.86	10.69	103.45	1.791.169
20	22.00	24.59	10.16	101.90	1.868.571
21	20.84	23.43	9.68	100.51	1.947.169
22	19.78	22.39	9.24	99.24	2.026.968
23	18.82	21.43	8.84	98.08	2.107.932
24	17.93	20.56	8.48	97.02	2.190.085
25	17.12	19.75	8.14	96.04	2.273.386
26	16.37	19.01	7.83	95.14	2.357.844
27	15.68	18.32	7.54	94.31	2.443.456
28	15.03	17.68	7.28	93.54	2.530.204
29	14.43	17.08	7.03	92.82	2.618.088
30	13.87	16.53	6.79	92.15	2.707.114
31	13.35	16.01	6.58	91.52	2.797.269
32	12.86	15.52	6.37	90.94	2.888.551
33	12.40	15.06	6.18	90.38	2.980.958
34	11.97	14.63	6.00	89.87	3.074.487
35	11.56	14.23	5.83	89.38	3.169.137

B.2 Values corresponding to Restricted Surge Tank

The Data corresponding to Figures (6.3) and (6.4) are given in Table (B.2.1).

Table B.2.1: The Data corresponding to Figures (6.3) and (6.4)

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	H_{tank} (m)	COST (TL)
13	4	14.28	16.18	11.01	64.89	745.961
14	4	12.72	14.63	10.01	63.02	783.164
15	4	11.40	13.31	9.15	61.43	821.658
16	4	10.27	12.19	8.42	60.07	861.342
17	4	9.30	11.22	7.78	58.90	902.140
18	4	8.45	10.38	7.22	57.89	944.007
19	4	7.71	9.65	6.73	57.00	986.875
20	4	7.05	9.00	6.29	56.21	1.030.703
21	4	6.47	8.42	5.90	55.51	1.075.454
22	4	5.95	7.91	5.55	54.89	1.121.130
23	4	5.48	7.45	5.23	54.33	1.167.678
24	4	5.06	7.03	4.94	53.83	1.215.102
25	4	4.69	6.66	4.68	53.37	1.263.369
26	4	4.34	6.32	4.45	52.96	1.312.478
27	4	4.03	6.01	4.23	52.59	1.362.418
28	4	3.74	5.73	4.03	52.24	1.413.176
29	4	3.48	5.47	3.84	51.93	1.464.744
30	4	3.24	5.23	3.67	51.64	1.517.120

The Data corresponding to Figures (6.5) and (6.6) are given in Table (B.2.2).

Table B.2.2: The Data corresponding to Figures (6.5) and (6.6)

D_{tank} (m)	D_{orf} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	H_{tank} (m)	COST (TL)
23	2	0.21	2.59	1.31	48.00	1.031.724
23	3	2.20	4.38	3.20	50.39	1.083.093
23	4	5.48	7.45	5.23	54.33	1.167.678
23	5	8.24	10.08	6.66	57.64	1.238.882
23	6	10.02	11.82	7.47	59.77	1.284.660
23	7	11.02	12.83	7.89	60.97	1.310.423
23	8	11.56	13.38	8.11	61.62	1.324.317
23	8.5	11.72	13.55	8.17	61.82	1.328.633

B.3 Values corresponding to Shafted Surge Tank Equations

The Data corresponding to Figures (6.7) and (6.8) are given in Table (B.3.1).

Table B.3.1: The Data corresponding to Figures (6.7) and (6.8)

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	H_{tank} (m)	H_{shaft} (m)	COST (TL)	H_{total} (m)
16	6	16.43	17.80	11.09	58.02	9.44	872.026	67.47
18	6	13.74	15.56	9.75	53.19	11.05	914.364	64.24
19	6	12.81	14.62	9.18	51.39	11.73	939.609	63.12
21	6	11.23	13.03	8.22	48.34	12.89	991.134	61.22
23	6	9.93	11.74	7.43	45.83	13.83	1.043.782	59.67
24	6	9.37	11.17	7.09	44.75	14.24	1.070.648	58.99
26	6	8.38	10.18	6.48	42.83	14.97	1.125.095	57.81
28	6	7.55	9.34	5.96	41.21	15.60	1.180.859	56.80
29	6	7.17	8.97	5.73	40.48	15.87	1.209.295	56.36

The Data corresponding to Figures (6.9) and (6.10) are given in Table (B.3.2).

Table B.3.2: The Data corresponding to Figures (6.9) and (6.10)

D_{tank} (m)	D_{shaft} (m)	y_{1max} (m)	y_{2max} (m)	y_{2min} (m)	H_{tank} (m)	H_{shaft} (m)	COST (TL)	H_{total} (m)
18	2	0.33	2.69	1.67	27.40	20.75	481.025	48.14
18	3	3.69	5.85	4.37	34.67	17.51	605.187	52.17
18	4	8.16	10.11	7.07	43.28	14.27	747.376	57.54
18	5	11.66	13.49	8.83	49.58	12.15	852.036	61.74
18	6	13.74	15.56	9.75	53.19	11.05	914.364	64.24
18	7	14.85	16.67	10.20	55.06	10.51	949.689	65.57
18	8	15.41	17.25	10.42	56.00	10.25	970.951	66.25
18	8.5	15.58	17.42	10.48	56.28	10.17	978.657	66.45

B.4 Values corresponding to D_{orf}/D_{tank} Comparison

The Data corresponding to Figure (6.13) in Table (B.4).

Table B.4: The Data corresponding to Figure (6.13)

D_{orf}/D_{tank}	D_{tank} (m)	H_{tank} (m)
0.10	29	80
0.11	28	80
0.11	27	80
0.12	26	81
0.12	25	81
0.13	24	82
0.13	23	82
0.14	21	84
0.14	22	83
0.14	28	85
0.14	29	85
0.15	27	86
0.15	20	85
0.15	26	86
0.16	19	86

D_{orf}/D_{tank}	D_{tank} (m)	H_{tank} (m)
0.16	25	87
0.17	18	87
0.17	23	89
0.17	24	88
0.17	29	88
0.18	17	88
0.18	28	89
0.18	22	90
0.19	16	89
0.19	21	91
0.19	26	91
0.19	27	90
0.20	15	91
0.20	20	92
0.20	25	91

Table B.4.continued: The Data corresponding to Figure (6.13)

D_{orf}/D_{tank}	D_{tank} (m)	H_{tank} (m)
0.21	14	93
0.21	19	93
0.21	24	92
0.21	28	91
0.21	29	91
0.22	23	93
0.22	18	95
0.22	27	92
0.23	22	94
0.23	26	93
0.24	17	97
0.24	21	96
0.24	25	94
0.24	29	92
0.25	16	99
0.25	20	97
0.25	24	95
0.25	28	93
0.26	27	93
0.26	23	96
0.26	19	99
0.27	15	101
0.27	22	97
0.27	26	94
0.28	29	92
0.28	18	100
0.28	25	95
0.29	14	104
0.29	17	102
0.29	21	98
0.29	24	96

D_{orf}/D_{tank}	D_{tank} (m)	H_{tank} (m)
0.29	28	93
0.30	27	94
0.30	20	100
0.30	23	97
0.31	26	95
0.31	29	93
0.31	16	104
0.32	19	101
0.32	22	98
0.32	25	96
0.32	28	94
0.33	15	107
0.33	18	103
0.33	21	100
0.33	24	97
0.33	27	94
0.35	17	105
0.35	20	101
0.35	23	98
0.35	26	95
0.36	14	110
0.36	25	96
0.36	22	99
0.37	19	102
0.38	16	107
0.38	21	100
0.38	24	97
0.39	18	104
0.39	23	98
0.40	15	109
0.40	20	102

Table B.4.continued: The Data corresponding to Figure (6.13)

D_{orf}/D_{tank}	D_{tank} (m)	H_{tank} (m)
0.41	22	99
0.41	17	106
0.42	19	103
0.43	14	112
0.43	21	101
0.44	16	108
0.44	18	105
0.45	20	102

D_{orf}/D_{tank}	D_{tank} (m)	H_{tank} (m)
0.47	15	111
0.47	17	107
0.47	19	103
0.50	16	109
0.50	18	105
0.53	17	107
0.56	16	109

B.5 Values corresponding to D_{shaft}/D_{tank} Comparison

The Data corresponding to Figure (6.14) in Table (B.5).

Table B.5: The Data corresponding to Figure (6.14)

D_{shaft}/D_{tank}	H_{tank} (m)	D_{tank} (m)
0.07	48	29
0.07	48	28
0.08	48	26
0.08	48	24
0.09	48	23
0.10	48	21
0.10	49	29
0.11	48	18
0.11	48	19
0.11	49	28
0.12	49	26
0.13	49	15
0.13	48	16
0.13	50	23
0.13	50	24
0.14	52	29
0.14	51	21
0.14	52	28

D_{shaft}/D_{tank}	H_{tank} (m)	D_{tank} (m)
0.15	49	13
0.15	53	26
0.16	52	19
0.17	50	12
0.17	52	18
0.17	54	23
0.17	54	24
0.17	54	29
0.18	55	28
0.19	53	16
0.19	55	21
0.19	56	26
0.20	51	10
0.20	54	15
0.21	57	19
0.21	57	24
0.21	57	28
0.21	56	29

Table B.5.continued: The Data corresponding to Figure (6.14)

D_{shaft}/D_{tank}	H_{tank} (m)	D_{tank} (m)
0.22	57	23
0.22	52	9
0.22	58	18
0.23	57	13
0.23	58	26
0.24	59	21
0.24	58	29
0.25	58	12
0.25	60	16
0.25	59	24
0.25	58	28
0.26	60	23
0.26	61	19
0.27	61	15
0.27	59	26
0.28	58	29
0.28	62	18
0.29	61	21
0.29	60	24
0.29	59	28
0.29	58	29
0.30	62	10
0.30	59	28
0.30	61	23

D_{shaft}/D_{tank}	H_{tank} (m)	D_{tank} (m)
0.31	64	13
0.31	64	16
0.31	60	26
0.32	63	19
0.33	67	15
0.33	64	18
0.33	63	21
0.33	61	24
0.33	60	26
0.35	62	23
0.35	61	24
0.37	64	19
0.37	62	23
0.38	67	16
0.38	63	21
0.39	66	18
0.40	63	21
0.42	65	19
0.44	69	16
0.44	66	18
0.45	65	19
0.47	66	18

APPENDIX C

FIGURE USED FOR VORTEX CALCULATIONS

Submergence depth, S is obtained from Figure (C.1). The third line corresponding to Pickford is used.

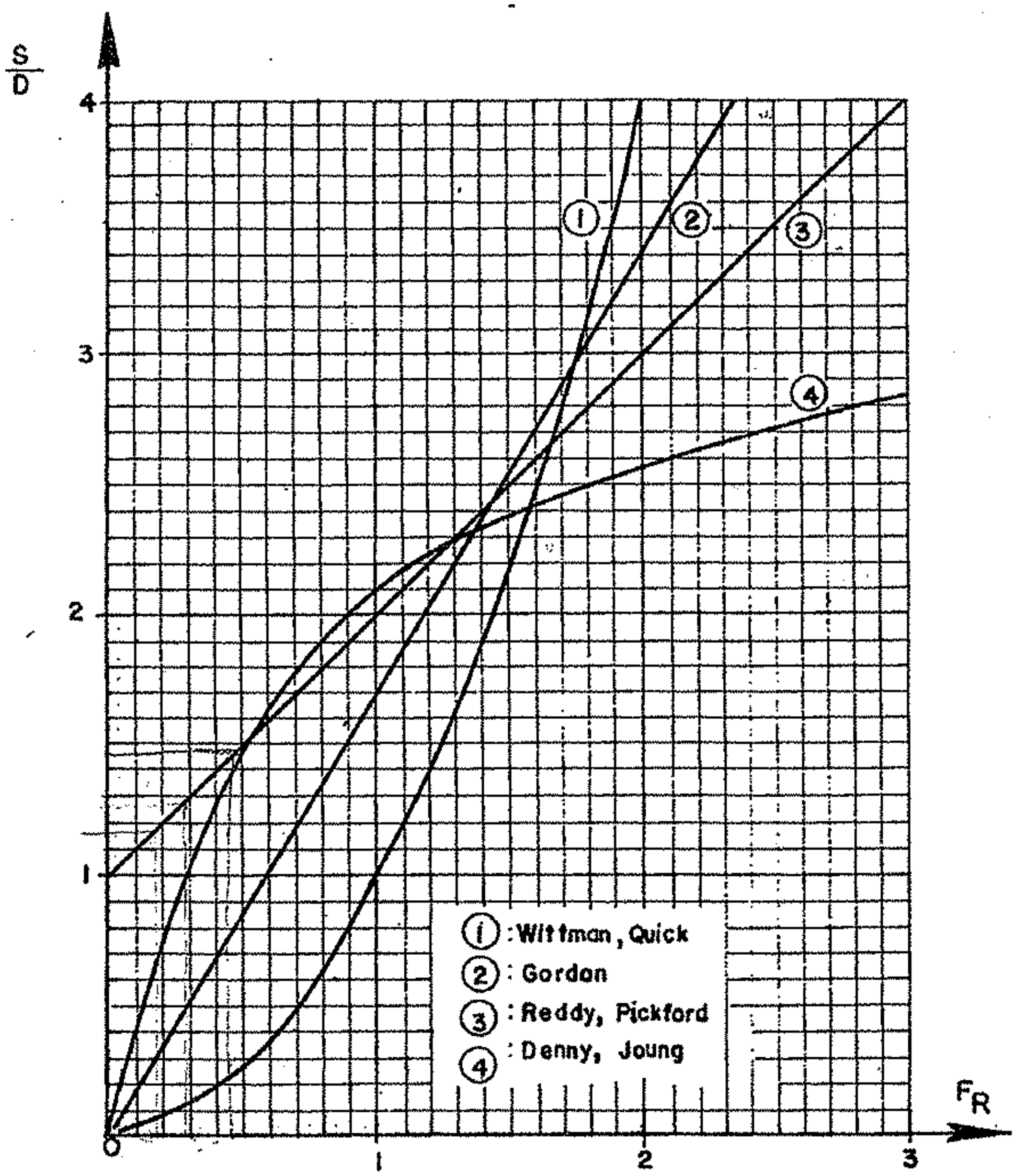

Figure C.1 The variation of the ratio S/D for different Froude numbers (Yıldız, 1992)

APPENDIX D

ACTUAL AND CALCULATED VALUES FOR THE DAMS USED IN THE DEVELOPMENT OF THE DIMENSIONLESS EQUATIONS

In Figure (D.1) the actual and the calculated values for the dams used in the development of the dimensionless equations are presented.

	Type	Q_{min} (m^3/s)	Q_{max} (m^3/s)	c_t	H_{resmax} (m)	H_{resmin} (m)	L_t (m)	D_t (m)	D_{tank} (m)	H_{tank} (m)	H_{tank} obt. (m)
Ermenek	simple	26	104	0,001789582	694	660	8064	5,6	10	142	144
Gezende	simple	29,25	117	0,001906138	333	310	8629	5,6	10	95	94
Atasu	simple	8	32	0,010048126	319,05	256	2600	3,3	7,5	100	102
Çine	shafted D_{shaft} = 3,9 m	9,75	35	0,004692479	264,8	205	2926	3,9	25	80	82
Example 1	shafted D_{shaft} = 6,5 m	150	250	0,000039339	450	425	700	8,5	22	62,75	61
Example 2	orifice D_{orf} = 6,7 m	100	240	0,000051742	445	410	2000	9	25	95,83	95
Example 3	simple	25	40	0,005448880	350	335	4000	4	15	53,5	52
Example 3	orifice D_{orf} = 2,8 m	25	40	0,00544888	350	335	4000	4	15	51,5	51

Figure D.1 The actual and the calculated values for the dams used in the development of the dimensionless equations