COMPUTER ASSISTED HYDRAULIC DESIGN OF TYROLEAN WEIRS

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COMPUTER ASSISTED HYDRAULIC DESIGN OF TYROLEAN WEIRS

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ABSTRACT

COMPUTER ASSISTED HYDRAULIC DESIGN OF TYROLEAN WEIRS

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Tyrolean weir is a type of water intake structure in which water is taken into the channel by bottom racks built on the stream bed. It is generally preferred in order to divert water to run-off river plants on mountainous regions with steep slopes where bed sediment concentration is rather high. In this study; a literature research is conducted in terms of assumptions, approaches, and different calculation methods used for designing a Tyrolean type of intake structure. Broadly accepted and tested design studies in literature are presented, practiced and compared regarding the type of approaches and assumptions made for related methods. A computer program is developed to perform design and analysis. In the design part, number of bars, their thickness, spacing and length are determined for the given design discharge to be diverted. In the analysis part of the program, flow depth over the trash rack is obtained and discharge taken into the intake channel is calculated by using stream discharge, trash rack length, bar types, and bar cross-sections as input values. An application study conducted to guide through the stages of analysis and design calculation methods.

Keywords: Tyrolean weir, intake structure, bottom intake, trash rack.

ÖZ

TİROL TİPİ SAVAKLARIN BİLGİSAYAR DESTEKLİ HİDROLİK TASARIMI

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Tirol tipi bağlamalar, suyun kanala akarsu tabanına kurulmuş ızgaralardan alındığı su alma yapılarıdır. Nehir tipi santrallerde, genellikle sürüntü yükünün nispeten fazla olduğu dağlık bölgelerdeki dik eğimli akarsularda tercih edilirler. Bu çalışmada; Tirol tipi su alma yapılarının tasarımı için kullanılan kabuller, yaklaşımlar ve farklı hesap yöntemleri üzerine bir literatür araştırması yapılmıştır. Literatürdeki ilgili metotların yaklaşım yöntemlerine ve varsayımlarına ilişkin kabul gören ve test edilmiş çalışmalar sunulmuş, uygulamaları yapılmış ve bu metotlar karşılaştırılmıştır. Tirol tipi su alma yapılarının tasarım ve analizini yapan bir bilgisayar programı geliştirilmiştir. Tasarım aşamasında, tasarım debisinin sağlanması için gerekli ızgara çubuklarının adedi, kalınlıkları, boşlukları ve uzunlukları belirlenmektedir. Programın analiz aşamasında ise akarsuyun debisini, ızgara uzunluğunu, çubukların boyu ve kesitlerini kullanarak ızgara üzerindeki su yüksekliği elde edilmekte ve su alma yapısına giren suyun debisi hesaplanmaktadır. Analiz ve tasarım hesap yöntemlerine rehberlik etmesi amacıyla bir de uygulama çalışması yapılmıştır.
Anahtar Kelimeler: Tirol tipi bağlama, su alma yapısı, tabandan su alma, ızgara.

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C_d	:	Discharge coefficient for an inclined Tyrolean screen
D	:	Diameter of the rack bars
d_{50}	:	Median gravel size
$(F_r)_e$	:	Froude number based on bar spacing
g	:	Gravitational acceleration
h_0	:	Flow depth at just upstream of the screen
h_c	:	Critical flow depth
H_0	:	The energy head of the flow at upstream of the screen
H_c	:	Critical energy head
ℓ	:	The required rack length to divert all incoming discharge
L	:	Length of the Tyrolean screen
L_1	:	distance where the axis of the trash rack crossed with the flow
L_2	:	Total wetted rack length
m	:	Clearance distance between bars of the Tyrolean screen
n	:	Center distance between two adjacent bars of the Tyrolean screen
$(q_w)_i$	:	Diverted unit discharge by the Tyrolean screen
q_{max}	:	Maximum discharge for the energy head
$(q_w)_{out}$	:	The discharge that passes over the trash rack
$(q_w)_T$	:	Total unit discharge in the main channel
s	:	Distance of any point away from the origin of ellipse
S_L	:	Slope of rack bars
t	:	Thickness of the bar
V_0	:	Velocity at approach
β	:	A function in Table 3.1
$\mathcal{E}$	:	Angle of inclination of the screen
λ	:	Discharge coefficient parameter
μ_s	:	Contraction coefficient

φ	:	A parameter which depends on maximum discharge
χ	:	Correction factor
ψ	:	The net rack opening area per unit width of the rack
ϕ	:	A function in Table 1

CHAPTER 1

INTRODUCTION AND GENERAL INFORMATION

1.1 Introduction

For water diversion purpose, many different types of intakes are being used depending on the geographical conditions, hydraulic factors, sediment concentrations and economical concerns.

Intake structure types can be mainly listed as follows (Yanmaz, 2013):

I. Lateral intakes

II. Frontal intakes

III. Bottom intakes

Tyrolean weirs are included in bottom intake type. The general working principle of a Tyrolean type of bottom intake is transferring the flow into the channel through the trash rack placed at the bed of the stream.

Tyrolean intakes are suitable for mountainous regions due to their ability to filter sediments by rack bars. They are mostly suited to run-off river power plants, which have limited storage capacity or no storage at all. This feature makes the structure cheaper and reduces the environmental impact on the nature.

However, the main handicap of run-off rivers is the sediment intrusion, since water is taken into the channel directly. Although settling basins are constructed after the intake section, their effectiveness in capturing the sediment is based on the amount and type of sediment entering the settling basin. As the slope of the river increases, sediment carrying capacity of the river increases and this situation becomes a very important problem since even a small particle of sediment can damage the turbine in a hydropower plant.

1.2 General Information

The trash rack in a Tyrolean weir is generally made of stainless bars in selected cross sections and lined in the same direction with the stream flow. Bars are placed with a constant spacing in-between which is wide enough to let the water pass through with the desired amount but also narrow enough to prevent coarse sediments to pass. The rack is placed with an inclination smoothly adapted to the stream bed and positioned above the channel which transfers the flow to the hydropower station.

Gravity is the governing force that diverts water into the channel by the spacing between bars. Sediment particles larger than the spacing are kept out of the system and excess water with the sediment load of the river follow the original stream direction over the inclined rack directly to the downstream.

In this study; a literature research is conducted and presented in chapter 2 in terms of assumptions, approaches, and different calculation methods used for designing a Tyrolean type of intake structure. In chapter 3, broadly accepted and tested design studies in literature are presented, practiced and compared regarding the type of approaches and assumptions made for related methods. Finally, a computer program is developed to design and analyze Tyrolean intakes and its working principles are explained in chapter 4. In the design interface of the program, inputs about the river are given and necessary parameters are selected. Then, dimensions and properties of rack bars are defined. In the analysis interface of the program, discharge taken into the channel and water surface profile is determined according to the predefined variable parameters by using different related studies, methods, and assumptions. An example study is conducted for both parts of this study to guide through the general design and analysis stages and to explain the working principles of the computer program in detail. These two application studies are presented in chapter 6 and finally in chapter 7 conclusions and recommendations are mentioned.

CHAPTER 2

LITERATURE REVIEW

Orth et al. (1954) provided the first study which describes bottom intakes. The study was on five different transverse rack geometries which are the simple T, the T with a top triangle profile, the semicircular shape with a vertical bar, the fully circular shape, and the ovoid profile. Flows on a 20% sloping channel are investigated and results have shown that, the worst water capture efficiency belonged to T-shaped bar, whereas the ovoid bar could satisfy the minimum structural length. In terms of clogging, the bottom slope had only a small effect when compared to the bar shape (Orth,et al., 1954).

The free surface profile over bottom racks have been presented for the first time in a computational approach by Kuntzmann and Bouvard (1954), assuming a conventional orifice equation and constant energy. Results gave an ordinary differential equation of the sixth degree which represents the distribution of the flow over the horizontal bottom rack (Kuntzmann and Bouvard, 1954).

Savoy region of the French Alps was chosen by Ract-Madoux et al. (1955) as the study area and bottom intakes are investigated in that location. Results of this study had shown that; for the design, discharge and sediment content is essential; bottom racks should be in the direction of flow and bar profile should be in rounded shape. To minimize the clogging, slope of the bars should be above 20%, and finally, for mountainous regions considering availability of coarse sediment, a clear bar spacing less than 0.10 m is appropriate (Ract-Madoux et al., 1955).

Noseda (1956) predicted the free-surface profile *h(x)*, with h as local flow depth and x as the stream wise coordinate by choosing trash rack slopes of 0, 0.1 and 0.2 with bars having T and L cross-sections. Noseda (1956) decided on an orifice equation. In contrast to usual orifice flow, the integrated flow depth over the outflow length was found to differ significantly with the upstream flow depth. The free-surface profile departed from the prediction involving hydrostatic pressure distribution (Noseda, 1956).

Effect of non-hydrostatic pressure distribution on racks is investigated by Mostkow (1957). Pressure distributions of the flow over the rack are also studied and surface curvature effect on the bottom rack is demonstrated (Mostkow, 1957).

Discharge coefficient is stated as a dependent variable which changes according to the flow depth by Dagan (1963). He assumed the velocity of flow in the stream only has horizontal components and by using that assumption, a first-order nonlinear differential equation is obtained (Dagan, 1963).

Venkataraman et al. (1979) studied on bottom racks which are used in small scale models with 25 l/s and lesser discharge values and width of 30 cm. Sharp crested rack profiles and a horizontal channel cross-section is used in experiments. Results show that, the flow depth decrease with increase in discharge coefficient. However, Froude number has no effect on discharge coefficient. In subcritical flow, energy decreases in a small amount but when the flow is supercritical the decrease in the energy is in a considerable amount (Venkatamaran et al., 1979).

Experiments conducted by Drobir (1981) on prototypes revealed the following design requirements

1. Bar space width is around 30 mm
2. Cross-sections of bar profiles are circular
3. For sediment deposition and clogging, calculated rack length should be multiplied by two in order to be on the safe side
4. Optimum rack slope is 20 to 30%
5. The required flow depth under the rack is determined from side channel flow (Drobir, 1981)

Subramanya and Shukla (1988) conducted their experiments on horizontal channel cross-section and subcritical upstream, supercritical downstream flows. The efficiency, which is the ratio of the discharge taken into the channel and the upstream discharge is considered and demonstrated to increase significantly as the ratio of the rack length and critical flow depth increases. Moreover, ratio of the clear bar spacing to bar diameter also increases with efficiency. Depending on the upstream and downstream flow conditions, Subramanya and Shukla (1988) classified flows over bottom racks into five categories and these categories are used to define the calculation approach. They also defined the required trash rack length to take all the discharge to the intake channel (Subramanya and Shukla, 1988).

Bianco and Ripellino (1994) conducted experiments on a model which is larger than the model used by Noseda (1956). Studies have shown that, scale does not have a significant effect on the results. Cross-section of the bar profiles used in these observations was semicircular with rectangular bottom reinforcement at the bottom (Bianco and Ripellino, 1994).

Özcan (1999) presented the theoretical solutions in two separate approaches which are based on constant energy level and constant energy head hypothesis.

Drobir et al. (1999) studied on a model with a scale of 1:10. The model's purpose was to measure the wetted rack length and to determine the effect of bar spacing. Four different slopes were used which are between 0 and 30% and five different unit discharge values are analyzed which are 0.25, 0.50, 1.00, 1.50 and 2.00 m^3/s/m. Drobir et al. (1999) divided the total rack length into two and defined them as L_1 and L_2 which are the distance where the axis of the trash rack crossed with the flow and the total wetted length over the trash rack, respectively (See Figure 2.1) (Drobir et al., 1999). In Figure 2.1, $(q_w)_T$ and $(q_w)_i$ are unit discharge in the river and unit discharge in the intake channel, respectively.

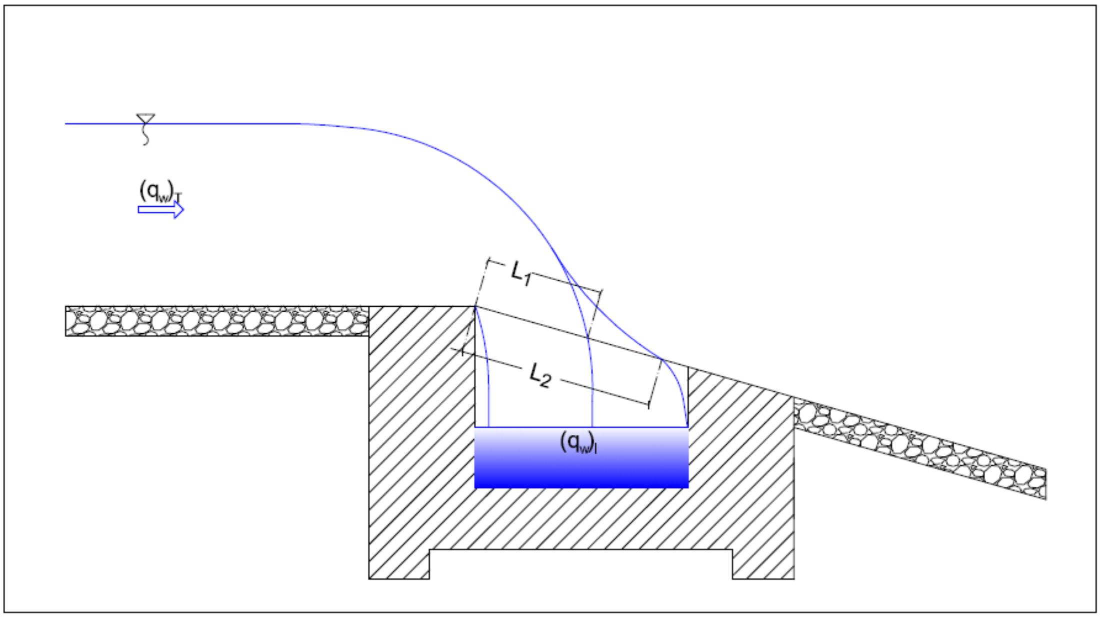


Figure 2.1 Sketch of rack lengths L_1 and L_2 of a Tyrolean screen (Drobir et al., 1999)

A rectangular channel with 0.5 m width and 7.0 m length was used in the experiments conducted by Brunella et al. (2003). The objective was to determine the effect of porosity, slope and geometry of the trash rack. The diameters of the bars were 12 mm and 6 mm and lengths of bars were 0.60 m and 0.45 m. They were placed with 6 mm and 3 mm clearance spacing with respect to each other. Angles of rack inclinations used in the experiment were Ɛ = 0, 7, 19, 28, 35, 39, 44 and 51 degrees. Results have shown that, surface profiles of the systems with large and small bottom slopes were almost identical.

Ghosh and Ahmad (2006) have studied on flat bars and they determined that the specific energy over the racks was nearly constant.

Kamanbedast and Bejestan (2008) conducted a series of experiments to determine the effects of screen slope and area opening of the screen on the diverted discharge. Dimensions of the model were 60 cm width, 8 m length and 60 cm height. Diameters of the bars used were 6 and 8 mm and spacing between bars were 30, 35 and 40% of total length. Inclinations were 10, 20, 30 and 40% and the model is tested by five different discharge values. Results have shown that, the discharge ratio increases as the slope of the rack increases. In addition to the slope, spacing is the second factor that affects the total flow taken into the channel. When the inclination is 30% and the spacing is 40% the discharge ratio reaches to a maximum value of 0.8. If the sediment is considered in the experiments it is observed that discharge ratio decreases to 90% of the without sediment condition. The reason of that reduction is the clogging of the bars (Kamanbedast and Bejestan, 2008).

A model is built and its behaviors are observed by Yılmaz (2010). In the experiments, circular bars with 1 cm diameter were used and three different spacing values and slopes are tested which are 3 mm, 6 mm and 10 mm; 14.5°, 9.6° and 4.8°, respectively (Yılmaz, 2010).

Metal panels with 3 mm, 6 mm and 10 mm diameter circular openings are tested as a trash rack on the same model by Şahiner (2012). Different than Yılmaz (2010), Şahiner (2012) used more steep slopes in his experiments, such as 37, 32.8 and 27.8 degrees.

Yılmaz (2010) and Şahiner (2012) prepared the graphs of variations of the discharge coefficient C_d, the ratio of the diverted discharge to the total water discharge, $[(q_w)_i/(q_w)_T]$, and the dimensionless wetted rack length, L_2/n, where n is the spacing between bars. The discharge taken into the channel can be calculated by using those graphs.

By experiments and investigations, many results have been obtained and different methods are designed to calculate the optimum parameters of Tyrolean intakes. Every approach has some assumptions and paths, so results can vary according to the method used. For example, friction effects are ignored due to small friction length over the trash rack. Surface tension of water between bars is also ignored. Furthermore, fluctuations in the flow depths over the rack bars are not considered in calculations.

In this study, design parameters and methods used in the past studies are collected and analyzed in detail. Solution methods can be summarized in four separate titles:

1. First Assumption: Constant Energy Level

    1.1 Iterative Method

    1.2 Closed Form Method

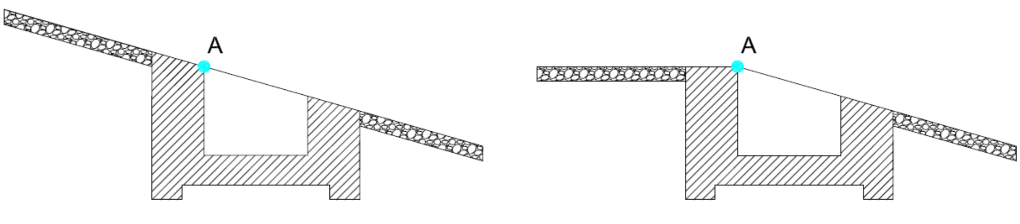
2. Second Assumption: Constant Energy Head

    2.1 Iterative Method

    2.2 Closed Form Method

If the trash rack is placed horizontally, both hypotheses become equal. But, the trash racks are designed to be inclined in projects. When the trash rack is arranged inclined, both hypothesis appear as boundary conditions. However, neither represents the exact solution.

These methods are used to determine the bars' length and spacing according to the desired discharge. For the sake of construction the upstream side of the trash rack can be considered horizontal or inclined as seen in Figure 2.2. In Figure 2.2.a, the critical depth and minimum energy is observed somewhere close to point A. However, in Figure 2.2.b, the critical depth is reached much earlier from point A and in this spot the flow has smaller depth. These two conditions must be separated from each other in hydraulic calculations.



a) b)

Figure 2.2 Tyrolean weirs with a) inclined and b) horizontal approaches

Calculation of the discharge that passes through the trash rack depends on the water surface profile over the weir. The discharge that passes from point A starts to drop into the collection channel and the discharge over the weir reduces along the trash rack. Flow over the trash rack is affected by friction of the bars and surface tension.

Trash racks are the most important part of Tyrolean Weirs. Efficiency as being the ratio of discharge transferred to the intake channel and total river flow is mostly related to the characteristics of rack bars. Bars are designed in three aspects which are; bar shape, spacing between bars, and bar length.

To increase the efficiency, screens should be stable and resistant to vibrations. Steel is mostly used as the material type of bars to be resistant to corrosion. If the gaps between bars are filled with sediment, less water passes through screens. This situation decreases the performance of the turbine since actual water amount is lesser than the desired discharge amount. The trash rack functions essentially as a filter. Any solid particle larger than the bar spacing are kept above the screen. So, bar type and dimensions should be carefully selected to prevent sediment transition and clogging of the racks.

Some typical profiles of racks for Tyrolean intake are as follows:

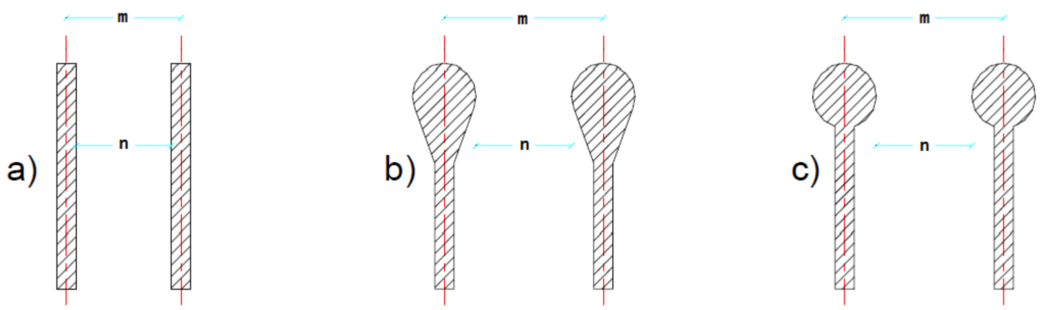


Figure 2.3 Types of rack bars with different profile a) Rectangular Bars b) Bulb-ended Bars c) Round-Headed Bars (Andaroodi, 2006)

Spacing between adjacent bars "*n*" and the center spacing "*m*" are the basic parameters used in the design calculations related with rack bars.

Andaroodi (2006) does not recommend the usage of rectangular bars due to their tendency to be clogged by stones. The bulb-ended bars can be preferred due to their higher performance and rigidity rates. However, the third alternative which is the round-head bars have more resistance to clogging and with higher moment of inertia they have more carrying capacity of heavy bed sediment loads (Andaroodi, 2006).

In experimental setups and models, bars with circular cross section can be used. However, streams can carry large amount of heavy boulders rolling and moving along the bed. The bottom rack bars have to be strong enough to carry the entire bed load which can contain big and heavy boulders (Ahmad and Mittal, 2006). So, round-head bars are the most suitable shape to be used in Tyrolean intake racks. The spacing between bars is recommended as 2 to 4 cm (Andaroodi, 2006).

Circular bars by rectangular reinforcement extension are the most efficient cross section. Moreover, circular bars extended by reinforcement give better performance rates in terms of clogging and vibration related problems. 30 to 40% bar spacing to avoid excessive clogging should be used. Gaps between bars are around 3 cm, depending on site conditions (Brunella et al., 2003).

CHAPTER 3

DESIGN AND ANALYSIS APPROACHES

This chapter provides basic information on computation of flow rate and water surface profile of Tyrolean Weirs. In the first two parts, constant energy level and constant energy head assumptions are explained in iterative and closed form solution methods. In the third part, trash rack design is described according to the past studies and assumptions made for the most efficient design.

3.1 The First Assumption: Constant Energy Level

As the solution procedures of the first assumption, calculations can be made iteratively or by a closed form method.

3.1.1 Iterative Solution Method:

As seen in Figure 3.2, the depth h_1 which occurs at the head of the trash rack is lower than h_0 which is the flow depth at approach. Firstly, the flow depth h_0 and the energy head H_0 must be calculated according to the unit discharge $(q_w)_T$. The energy level is constant along the trash rack and calculations begin where the water depth is h_1.

Equation (3.1) can be written by using the energy equation according to the unit width with length x_i, depth h_i and unit discharge q_i over the trash rack (Noseda, 1956).

$$q_i = h_i\sqrt{2g(H_i - h_i\cos\varepsilon)} \quad (3.1)$$

In Equation (3.1), ε is the angle of inclination of the bars with respect to the horizontal axis. To find the energy head H_i, elevation difference $x_i.sin(\varepsilon)$ must be added to the energy head H_0. After that, for depth h_{i+1}, which is searched for, a new assumption is made. To calculate the discharge $(q_w)_i$ that passes through Δx_i, system is solved as an orifice flow, and the following equation is given by using the flow depth at that section (Noseda, 1956).

$$(q_w)_i = \lambda \sqrt{h} (\Delta x_i) \tag{3.2}$$

where

$$\lambda = \psi \mu_s \sqrt{2g \cos \varepsilon} \tag{3.3}$$

The net rack opening area per unit width of the rack is $\psi = n / m$ in which n is the clearance distance and m is the center to center distance between two adjacent bars of the rack.

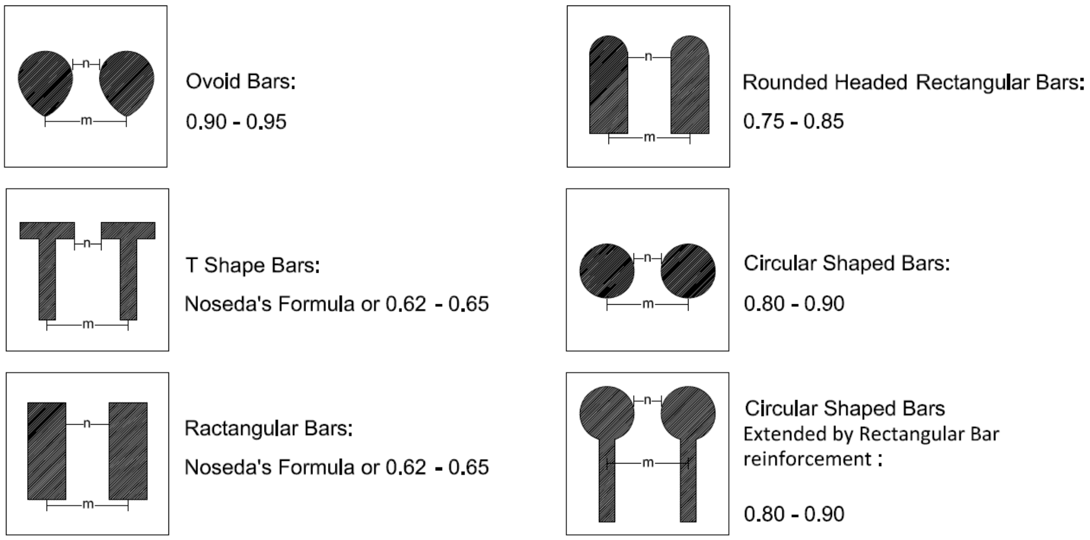


Figure 3.1 Bar types and related μ_s (contraction coefficient) values for calculation methods (Schmidt and Lauterjung, 1989)

For $0.2 < \frac{h}{m} < 3.5$, Noseda (1956) defines μ_s as follows;

$$\mu_s = 0.66\psi^{-0.16}\left(\frac{m}{h}\right)^{0.13} \tag{3.4}$$

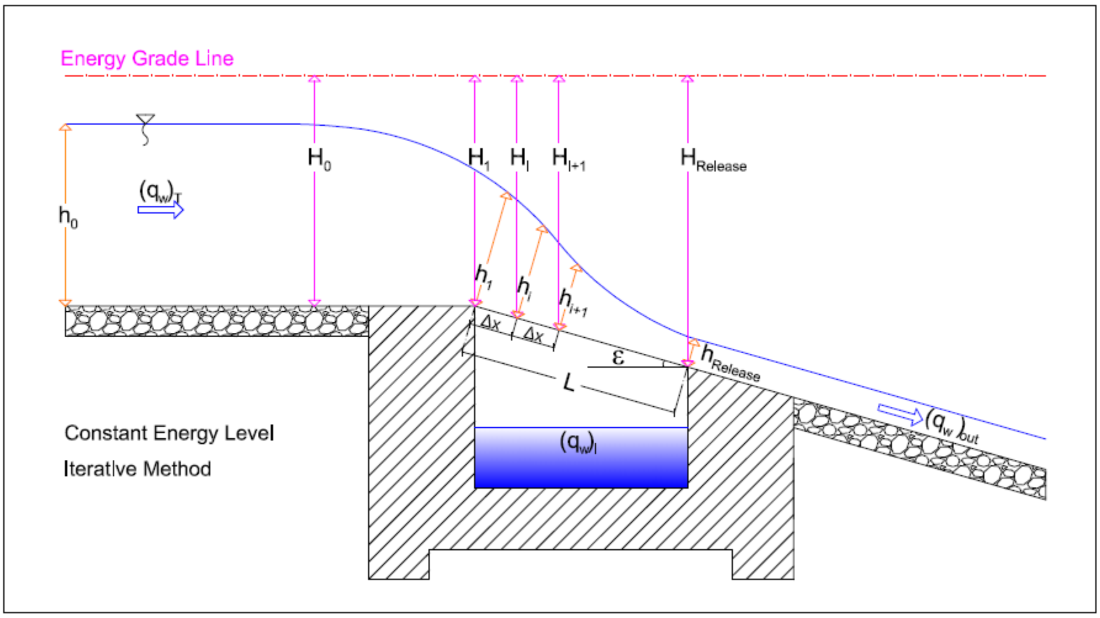


Figure 3.2 Constant energy level, weir system cross-section (Noseda, 1955)

In Equation (3.2) and Equation (3.4) the flow depth *(h)* is assumed as the average depth of h_i and h_{i+1} for Δx_i interval. Then, $(q_w)_i$ the discharge that passes between bars and goes into the intake channel is calculated and subtracted from the discharge passing over the interval Δx which is q_i, to calculate the discharge passing over the next interval, q_{i+1}. For each interval step, this iteration is applied.

3.1.2 Closed Form Solution Method:

Iterative method needs a freat amount of time and effort to solve. Frank (1956) developed a closed solution with some assumptions (Çeçen, 1962). In this approach, the change in the flow depth is accepted as elliptic. As seen in Figure 3.3, when all the incoming discharge is diverted, $((q_w)_T=(q_w)_i)$, and h_1 and axis of the ellipse are defined, it is possible to write Equation (3.5)

$$\frac{s^2}{l^2}=2\frac{h}{h_1}-\frac{h^2}{{h_1}^2} \tag{3.5}$$

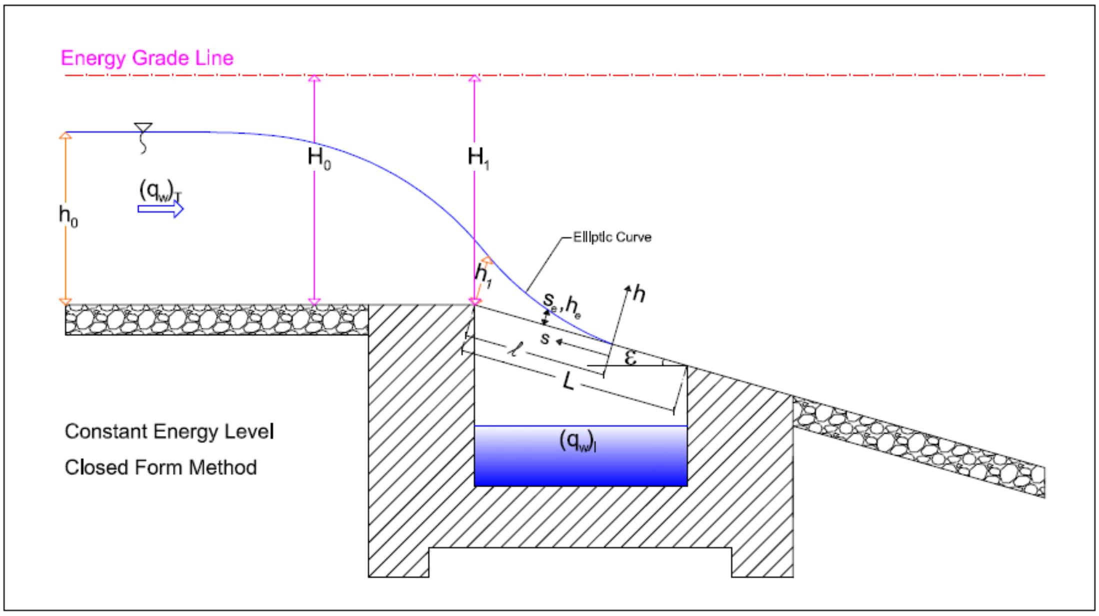


Figure 3.3 Hydraulic system of trash rack in closed form solution (Frank, 1956)

For $(q_w)_T=(q_w)_i$, any distance s_e away from the origin of the ellipse can be computed by using Equation (3.6) (Frank, 1956)

$$s_e=\sqrt{2\frac{l^2}{h_1}h_e-\frac{l^2}{{h_1}^2}{h_e}^2} \tag{3.6}$$

where h_e is the flow depth at distance s_e. The amount of water entered the collection channel through the distance ds_e can be found with the help of Equation (3.6)

$$ds_e=\frac{l}{h_1}\frac{(h_1-h_e)}{\sqrt{2h_1h_e-{h_e}^2}}dh_e \tag{3.7}$$

The differential discharge can be written as:

$$dq = \lambda\sqrt{h_0}\,ds_e = \lambda\frac{l}{h_1}\frac{\sqrt{h_e}\left(h_1 - h_e\right)}{\sqrt{2h_1h_e - h_e^{\,2}}}\,dh_e \tag{3.8}$$

Equation (3.8) can be integrated as follows:

$$(q_w)_i = \int dq = \lambda\frac{l}{h_1}\int_{h_e=0}^{h_e=h_1}\frac{\sqrt{h_e}\left(h_1 - h_e\right)}{\sqrt{2h_1h_e - h_e^{\,2}}}\,dh_e \tag{3.9}$$

which can finally result in:

$$(q_w)_i = \frac{2}{3}\lambda\sqrt{h_1}\,l\left(1+\frac{h_e}{h_1}\right)\sqrt{2-\frac{h_e}{h_1}}\;\Bigg|_{h_e=0}^{h_e=h_1} \tag{3.10}$$

or this equation can be simplified to

$$(q_w)_i = \frac{2}{3}\lambda\sqrt{h_1}\,l\left(2-\sqrt{2}\right) = 0.391\lambda\sqrt{h_1}\,l \tag{3.11}$$

For $(q_w)_i = (q_w)_T$, the wetted length can be computed as shown in Equation (3.12) (Frank, 1956).

$$l = 2.561\frac{(q_w)_T}{\lambda\sqrt{h_1}} \tag{3.12}$$

As seen in Figure 3.4, if the total discharge $(q_w)_T$ is not taken into the collection channel, according to Frank (1956), elliptic approach can be used to calculate the design parameters. In these cases, the length of the elliptic curve is computed by using the incoming discharge, $(q_w)_T$ and energy H_0. The length between where the flow depth is zero and the end of trash rack is $s = \ell - L$.

The diverted discharge $(q_w)_i$ can be calculated by making the following assumptions about elliptic curve approach (Frank, 1956).

1. The hatched area under the elliptic curve after the depth h_2 is accepted as the total discharge that goes to downstream (See Figure 3.4).

2. The area under the elliptic curve between the depth h_1 and h_2 is accepted as the discharge diverted into the collection channel.

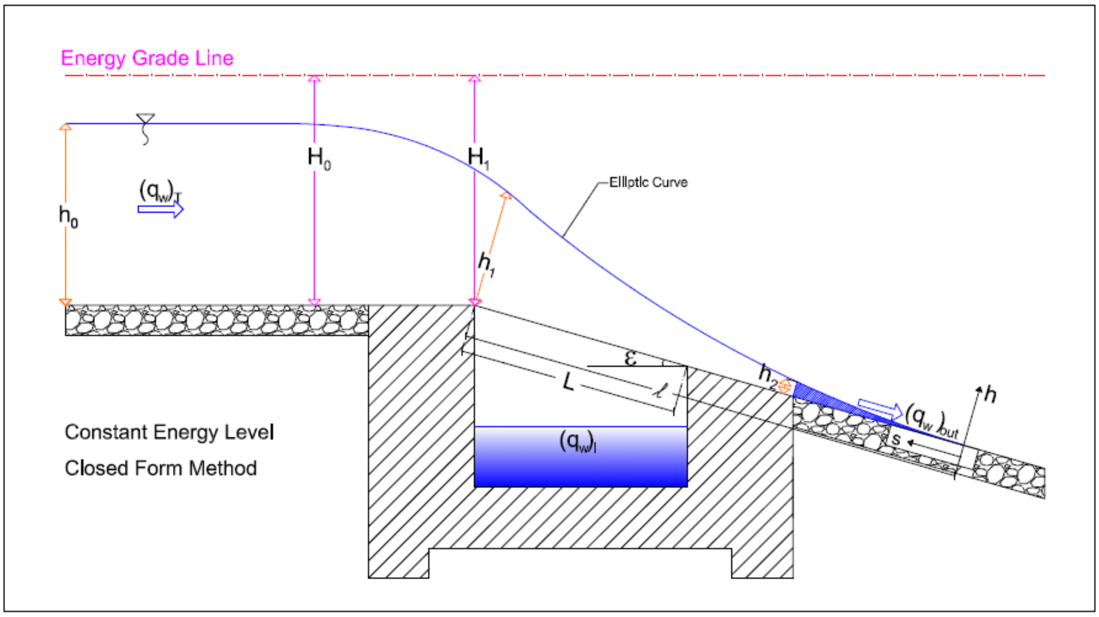


Figure 3.4 Elliptic curve approach, in cases where the total flow cannot be diverted (Frank, 1956)

By modifying Equation (3.10), Equation (3.13) is obtained.

$$(q_w)_i = \frac{2}{3}\lambda\sqrt{h_1}\,l\left(1+\frac{h_e}{h_1}\right)\sqrt{2-\frac{h_e}{h_1}}\;\Bigg|_{h_e=h_2}^{h_e=h_1} \qquad (3.13)$$

Then Equation (3.13) can be simplified as:

$$(q_w)_i = \frac{2}{3}\lambda\sqrt{h_1}l\left[2-\left(1+\frac{h_2}{h_1}\right)\left(\sqrt{2-\frac{h_2}{h_1}}\right)\right] \tag{3.14}$$

From Equation (3.12), Equation (3.14) can be obtained. The final form of the closed form solution formula is as follows:

$$(q_w)_i = 1.707(q_w)_T\left[2-\left(1+\frac{h_2}{h_1}\right)\left(\sqrt{2-\frac{h_2}{h_1}}\right)\right] \tag{3.15}$$

3.2 The Second Assumption: Constant Energy Head Value

In this approach, the head is assumed to be constant. Slope of the energy grade line is assumed to be equal to the inclination angle of the trash rack. Figure 3.5 shows the typical cross-section for constant energy head.

3.2.1 Iterative Solution Method

Noseda (1955) defined the differential equation of the water surface as in Equation (3.16), when inclination angle of the trash rack $\mathcal{E}$ is sufficiently small ($h \approx h\cos\mathcal{E}$) (Çeçen, 1962).

$$\frac{dh}{dx} = -\frac{2\mu_s\psi\sqrt{H_0(H_0-h)}}{2H_0-3h} \tag{3.16}$$

Equation (3.16) can be integrated directly between i and j points by assuming μ_s has a constant value. This integration has a closed form solution.

$$x_j - x_i = \frac{H_0}{\mu_s\psi}\left[\phi\left(\frac{h_j}{H_0}\right)-\phi\left(\frac{h_i}{H_0}\right)\right] \tag{3.17}$$

where

$$\phi\left(\frac{h}{H_0}\right) = \frac{1}{2}\arccos\left(\sqrt{\frac{h}{H_0}}\right) - \frac{3}{2}\sqrt{\frac{h}{H_0} - \left(1 - \frac{h}{H_0}\right)} \tag{3.18}$$

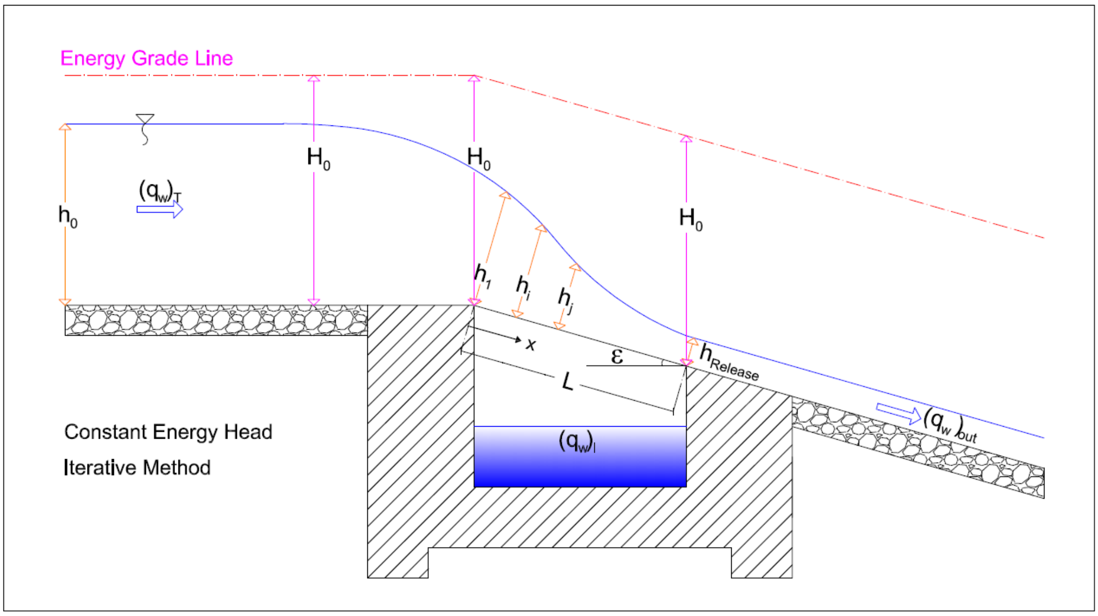


Figure 3.5 Constant energy approach scheme (Noseda, 1956)

The solutions of the function in terms of $\phi\left(\frac{h}{H_0}\right)$ and $\left(\frac{h}{H_0}\right)$ are given in Table 3.1.

The value of μ_s which is the contraction coefficient can also be calculated iteratively by using the h_{ave}, where h_{ave} is the average of flow depths h_i and h_{i+1}. This approach gives a better result than assuming a constant value of μ_s.

In this approach, it is recommended that the calculations must be completed step by step. Not only the flow depth, but also the discharges at selected points can be calculated by determining the maximum discharge (q_{max}) for energy H_0.

$$q_{\max} = h_c V_c = \frac{2}{3} H_0 \sqrt{2g\left(H_0 - \frac{2}{3} H_0\right)} = \frac{2\sqrt{2g}}{3\sqrt{3}} H_0^{3/2} = 1.705 H_0^{3/2} \qquad (3.19)$$

When Equation (3.17) is modified for q_{max}, Equation (3.20) is obtained.

$$x_j - x_i = \frac{H_0}{\mu_s \psi}\left[\beta\left(\frac{q_j}{q_{\max}}\right) - \beta\left(\frac{q_i}{q_{\max}}\right)\right] \qquad (3.20)$$

The closed form of Equation (3.20) can be written as;

$$\beta\left(\frac{q}{q_{\max}}\right) = \frac{1}{2}\arccos\left(\frac{1}{\sqrt{3}}\sqrt{2\cos\varphi + 1}\right) - \frac{\sqrt{2}}{2}\sqrt{(2\cos\varphi + 1)(1 - \cos\varphi)} \qquad (3.21)$$

where φ angle is a parameter which depends on maximum discharge.

Solutions of β function in terms of $\beta\left(\frac{q}{q_{\max}}\right)$ are given in Table 3.1.

φ is calculated separately for subcritical and supercritical flow cases.

For subcritical flow case:

$$\varphi = \frac{1}{3}\arccos\left[1 - 2\left(\frac{q}{q_{\max}}\right)^2\right] \qquad (3.22)$$

For supercritical flow case:

$$\varphi = \frac{1}{3}\arccos\left[1 - 2\left(\frac{q}{q_{\max}}\right)^2\right] + 240^{\circ} \qquad (3.23)$$

Table 3.1 Solutions of functions ϕ and β (Noseda, 1955)

$\left(\frac{h}{H_0}\right)$	$\phi\left(\frac{h}{H_0}\right)$	$\left(\frac{q}{q_{max}}\right)$	$\beta\left(\frac{q}{q_{max}}\right)$	
			Subcritical	Supercritical
0	0.7854	0	0	0.7854
0.05	0.3457	0.05	-0.0192	0.5084
0.10	0.1745	0.10	-0.0385	0.3937
0.15	0.0510	0.15	-0.0578	0.3072
0.20	-0.0464	0.20	-0.0771	0.2342
0.25	-0.1259	0.25	-0.0965	0.1702
0.30	-0.1921	0.30	-0.1158	0.1127
0.35	-0.2466	0.35	-0.1352	0.0617
0.40	-0.2918	0.40	-0.1546	0.0117
0.45	-0.3290	0.45	-0.1742	-0.0337
0.50	-0.3573	0.50	-0.1938	-0.0762
0.55	-0.3791	0.55	-0.2134	-0.1162
0.60	-0.3925	0.60	-0.2332	-0.1543
0.65	-0.3989	0.65	-0.2532	-0.1904
0.70	-0.3976	0.70	-0.2732	-0.2247
0.75	-0.3877	0.75	-0.2934	-0.2575
0.80	-0.3682	0.80	-0.3139	-0.2887
0.85	-0.3367	0.85	-0.3346	-0.3187
0.90	-0.2891	0.90	-0.3556	-0.3471
0.95	-0.2142	0.95	-0.3771	-0.3743
1.00	0	1.00	-0.3994	-0.3994

3.2.2 Closed Form Solution Method:

The closed form solution of constant energy method is produced by ignoring headlosses in the system. Slope of the energy grade line is assumed to be equal to the slope of the trash rack.

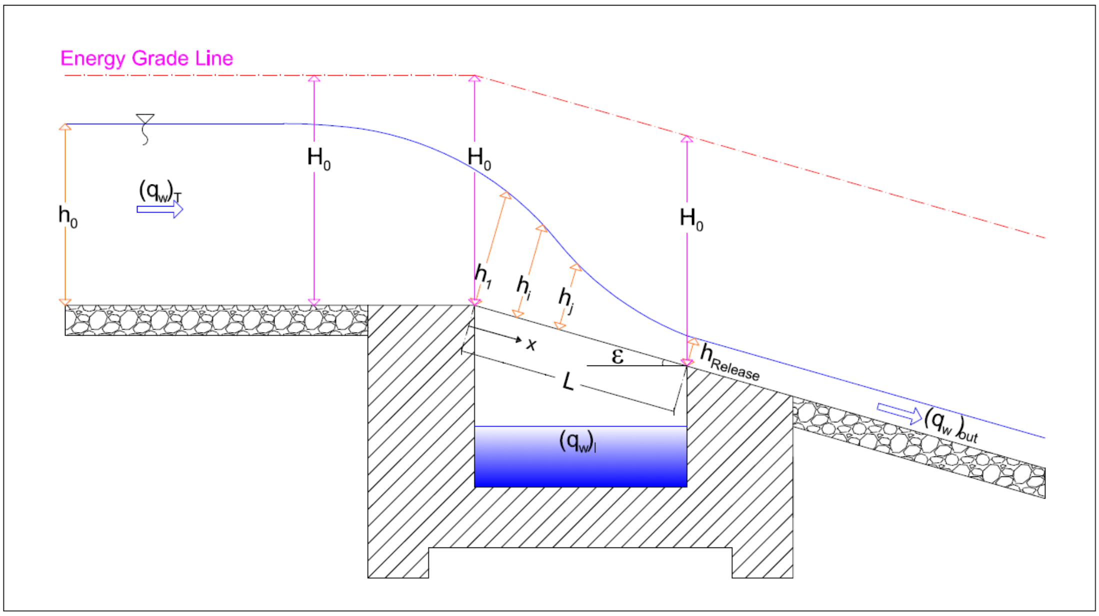


Figure 3.6 Constant energy head approach closed form solution scheme (Noseda, 1956)

Assuming the specific energy of flow to be constant all over the longitudinal bottom rack, Mostkow (1957) proposed the following equation for the diverted discharge into the trench:

$$(Q_w)_i = C_d \psi B L \sqrt{2gH_0} \tag{3.24}$$

where ψ = ratio of clear opening area and total area of the rack; B = length of the trench; L = length of the rack bars; g = acceleration due to gravity; H_0 = specific energy at approach; and C_d = coefficient of discharge. Based on limited experimental study, Mostkow (1957) suggested that C_d varies from 0.435, for a sloping rack 1 in 5, to 0.497 for a horizontal rack. However, geometrical and hydraulic aspects of the phenomenon were not completely considered by him. Noseda (1956), with an additional assumption of critical approach flow condition, analyzed the flow over longitudinal racks and presented a design chart relating the diverted flow to the total stream flow (Ahmad and Mittal, 2006).

White et al. (1972) conducted experiments and compared the trash racks with different lengths of bars, bar spacing and slope, with those resulted by Noseda's method. They suggested a different chart based on their studies, but their design chart is of limited application capability (White et al., 1972).

Subramanya and Shukla (1988) and Subramanya (1990, 1994) classified the flows over horizontal and sloping racks of rounded bars, which are listed in Table 3.2.

Table 3.2 Nature of flow over a bottom rack (After Subramanya 1990, 1994)

Type	***Approach***	***Flow Over The Rack***	***Downstream State***
AA1	Subcritical	Supercritical	May be a jump
AA2	Subcritical	Partially Supercritical	Subcritical
AA3	Subcritical	Subcritical	Subcritical
BB1	Supercritical	Supercritical	May be a jump
BB2	Supercritical	Partially Supercritical	Subcritical

The functional relationships for the variation of C_d in various types of flows are as follows:

a) Inclined Racks (Subramanya, 1994):

AA1 Type Flow

$$C_d = 0.53 + 0.4 \log \frac{D}{n} - 0.61 S_L \qquad (3.25)$$

BB1 Type Flow

$$C_d = 0.39 + 0.27\log\frac{D}{n} - \frac{0.8V_0^2}{2gH_0} - 0.5logS_L \qquad (3.26)$$

b) Horizontal Racks (Subramanya, 1990):

AA1 Type Flow

$$C_d = 0.601 + 0.2\log\frac{D}{n} - 0.247\frac{V_0^2}{2gH_0} \qquad (3.27)$$

AA3 Type Flow

$$C_d = 0.752 + 0.28\log\frac{D}{n} - 0.565\frac{V_0^2}{2gH_0} \qquad (3.28)$$

BB1 Type Flow

$$C_d = 1.115 + 0.36\log\frac{D}{n} - 1.084\frac{V_0^2}{2gH_0} \qquad (3.29)$$

where D = diameter of rack bars; n = spacing of rack bars; S_L = slope of rack bars; and V_0 = velocity at approach. The energy loss over the rack is not significant in Type AA3 flows; however, it is significant in other types of flows.

Ghosh and Ahmad (2006) studied experimentally the discharge characteristics of flat bars. They found that the specific energy over the rack is almost constant. Equation (3.24) can be used for longitudinal bottom racks of flat bars too. They also compared C_d obtained for flat bars with C_d calculated by Subramanya's (1994) relationship. Such comparison is shown in Figure 3.7. It is revealed from Figure 3.7 that the two sets of C_d values are different and Subramanya's relationship overestimates the value of C_d. Therefore, Equation (3.25), demonstrating the condition for rounded bars cannot be used for flat bars (Ahmad and Mittal, 2006).

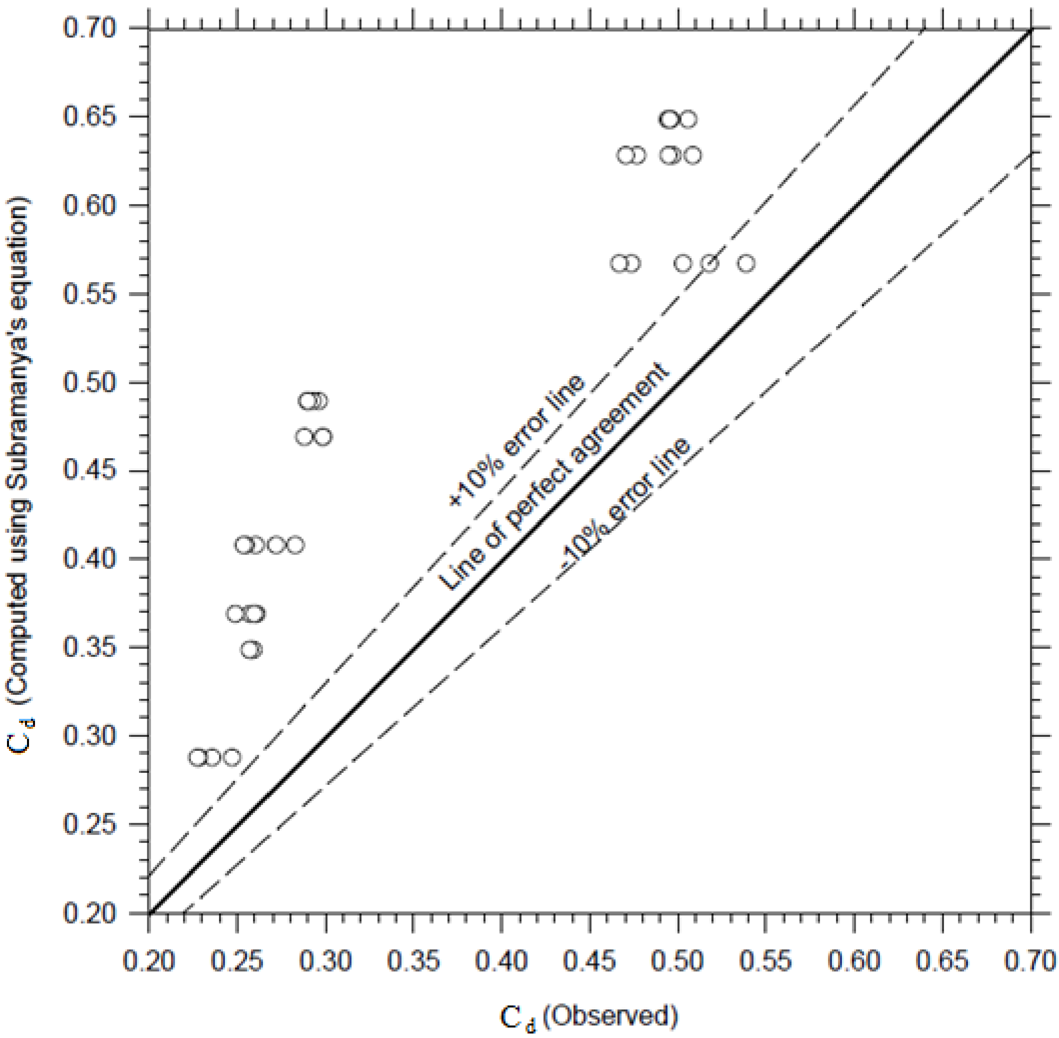


Figure 3.7 Verification of Subramanya's (1990) relationship for C_d

There is considerable effect of ratio of bar thickness *t* and clear spacing. The value of C_d increases with increase of *t/n* ratio; however, it decreases with the increase of inclination of bars (S_L) for constant value of *t/n* ratio. Ghosh and Ahmad (2006) proposed the following equation for C_d for flat bars:

$$C_d = 0.1296\left(\frac{t}{n}\right) - 0.4284 * S_L^2 + 0.1764 \qquad (3.30)$$

Equation (3.30) calculates the value of C_d for flat bars within ±10% error. Thus for the design of bottom racks with flat bars Equation (3.30) is recommended. The above equations can only be applied for free flow condition in the trench. However, if the discharge in the stream is more than the withdrawal discharge, submerged flow situation occurs and Equation (3.24) will be no more applicable. Submerged conditions need further studies.

Once the value of C_d is known, the length of the bottom rack is calculated using Equation (3.24). The optimum length of bottom rack which is also equal to the width of the channel trench, is obtained when diverted discharge is equal to the incoming discharge in the stream (Ahmad and Mittal, 2006).

For a given x interval, to determine the amount of water that passes through the trash rack, $(q_w)_i$, can be calculated as an orifice flow, by the following formula;

$$(q_w)_i = C_d \psi \sqrt{2gH_0}\, x \tag{3.31}$$

$(q_w)_T$ can be written as follows with the help of Equation (3.1) for $\mathcal{E}=0^o$.

$$(q_w)_T = h\sqrt{2g(H_0 - h)} \tag{3.32}$$

For an interval dx, the reduction in amount of water that passes over the trash rack equals to the amount of diverted water through the trash rack.

$$\frac{d(q_w)_i}{dx} = -\frac{d(q_w)_T}{dx} = C_d \psi \sqrt{2gH_0} \tag{3.33}$$

and the derivative of the stream discharge with respect to the depth of water is

$$\frac{d(q_w)_T}{dh} = \frac{2gH_0 - 3gh}{\sqrt{2gH_0 - 2gh}} \tag{3.34}$$

By inserting Equation (3.33) into Equation (3.34), Equation (3.35) is obtained.

$$\frac{3gh - 2gH_0}{\sqrt{2gH_0 - 2gh}} dh = C_d \psi \sqrt{2gH_0} dx \tag{3.35}$$

By using Equation (3.35), the relation between the head of the trash rack (h=h_1 and x=0) and any point on the trash rack at distance x from the head with the flow depth h can be written as follows;

$$\int_{h=h_1}^{h=h} \frac{3h - 2H_0}{\sqrt{(H_0 - h)}} dh = 2C_d \psi \sqrt{H_0} \int_{x=0}^{x=x} dx \tag{3.36}$$

after integrating the left side of the equation, the following equation is obtained.

$$-2h\left(\sqrt{H_0 - h}\right)\Big|_{h=h_1}^{h=h} = 2C_d \psi \sqrt{H_0}\, x \tag{3.37}$$

This equation is simplified as follows:

$$h_1 \sqrt{1 - \frac{h_1}{H_0}} - h\sqrt{1 - \frac{h}{H_0}} = C_d \psi x \tag{3.38}$$

By multiplying each side of the equation with $\frac{1}{H_0}$, the expression for $\frac{x}{H_0}$ can be obtained as follows.

$$\frac{x}{H_0} = \frac{1}{C_d \psi}\left(\frac{h_1}{H_0}\sqrt{1 - \frac{h_1}{H_0}} - \frac{h}{H_0}\sqrt{1 - \frac{h}{H_0}}\right) \tag{3.39}$$

By using Equation (3.39) water surface profile of the flow can be calculated. When x is selected as the full length of the trash rack, (L), the flow depth h_2 can also be computed.

$$(q_w)_{out} = h_2 \sqrt{2g(H_0 - h_2)} \tag{3.40}$$

So the discharge that is diverted into the collection channel can be calculated by

$$(q_w)_i = (q_w)_T - (q_w)_{out} \tag{3.41}$$

3.3 Trash Rack Design

The discharge taken into the intake channel of a Tyrolean weir mostly depends on the trash rack properties. Its length, slope and spacing and diameter of bars are the main parameters which affect the water taking efficiency of a Tyrolean intake structure.

The design discharge which will be taken into the turbine should be determined according to the assumption that, at least the 10% of water will pass to the downstream of the structure as should be in any hydraulic structure for the sake of protection of the environment.

To design the Tyrolean intake, best approach is to assume a 100% intake ratio to supply the design discharge (Brunella et al., 2003). So, rack length and other design parameters are determined according to the scenario that all of the stream flow is transferred to the intake channel. Although, the real discharge will be larger than the design discharge and at least 10% of the flow should be passing to the downstream since the design will be done in order to take only the required amount of water. This procedure is the main idea of the design stage.

There are different methods to calculate the necessary rack length which will be required to take the design discharge into the intake channel. Frank (1956) assumed no head loss while water is passing over bars and derived a formula to obtain the length of the rack. By using Equation (3.12), rack length can be calculated. $(q_w)_T$ is the total discharge flowing in the stream, λ is as described in Equation (3.3) and h_1 is the flow depth just at the upstream of the rack. $h_1=\chi\ h_{cr}$, where χ is the reduction factor. This factor can be calculated by using Equation (3.42).

$$(2cos\varepsilon)\chi^3 - \chi^2 + 1 = 0 \qquad (3.42)$$

in which $\mathcal{E}$ is the inclination angle of bars and h_{cr} is the critical flow depth.

$$h_{cr} = \sqrt[3]{\frac{(q_w)_T^2}{g}}$$

Noseda (1956), derived the Equation (3.43) to calculate the trash rack length by assuming constant energy head.

$$L = 1.185\frac{H_0}{1.22\mu\psi} \qquad (3.43)$$

However, this equation is based on the horizontal rack assumption.

Another study, submitted by Mostkow (1957) which is shown in Equation (3.44) is obtained according to the constant energy level assumption.

$$L = \frac{q}{C_d\ \psi\ cos\varepsilon\ \sqrt{2gH_0}} \qquad (3.44)$$

Mostkow (1957) suggested the discharge coefficient, C_d between 0.497 and 0.609 for horizontal racks, 0.435 and 0.519 for 20% inclined rectangular bars.

Finally, the formula suggested by Brunella et al. (2003) for the calculation of rack length is given in Equation (3.45).

$$L = 0.83\frac{H_0}{C_d\psi} \qquad (3.45)$$

where C_d, the discharge coefficient is equal to 1.1 for porosity values, $\Psi = 0.35$ and $C_d = 0.87$ for , $\Psi = 0.664$. The constant value, 0.83 in Equation (3.45) can be taken as 1.0 for the design calculation to be on the safe side in terms of clogging issues (Brunella et al., 2003).

Formulae which are used for calculating the rack length give overestimated results. However, the formula given by Mostkow (1957) and Brunella et al. (2003) gives logical results (Jiménez and Vargas, 2006).

There are many approaches to calculate the length of bars and they depend on variables varying according to the researcher's assumptions and design criteria. So, while designing the intake, rack length is not only calculated by these formulae but also checked by using the previously explained analysis methods.

Rack length will be just long enough to take the necessary discharge. To calculate the rack length, other design parameters like bar diameters, bar spacing and slope of the rack should be known.

To begin with, some specific assumptions can be made to determine bar dimensions. According to experiments and studies, to obtain the most efficient hydraulic design bar spacing ratio should be 40% (Aghamajidi and Heydari, 2014).

So, the ratio $\psi = n/m$ should be equal to 40%. The purpose of bar spacing n, is to prevent entry of large bed load particles. Common practice is to block particles larger than median gravel size which are between 2 and 4 cm. So, a spacing of 3 cm is advised (Raudkivi, 1993). In the design stage, designer should know the median gravel size to decide on the bar spacing or manually a predefined bar spacing can be assumed and calculations can be made accordingly. If 4 cm spacing between bars is assumed, then a diameter of 6 cm gives the most hydraulic performance according to the suggested 40% ratio.

Also, according to Brunella et al. (2003), circular bars by rectangular reinforcement extension are the most efficient cross section. Moreover, circular bars extended by reinforcement give better performance rates in terms of clogging and vibration related problems. 30 to 40% bar spacing to avoid excessive clogging should be used. Gaps between bars should be around 3 cm, depending on site conditions (Brunella et al., 2003).

Andaroodi (2006) suggested round-head bars as being the most appropriate type in terms of clogging and durability against heavy and large bed load elements because of higher moment of inertia. The recommended bar spacing for circular bars with reinforcement is 2 to 4 cm (Andaroodi, 2006).

In this study, rack openings are designed according to the median gravel size. If it is below 2 cm, spacing between bars are 2 cm. If it is above 4 cm, gaps are decided to be 4 cm, since these values are the suggested range. Any other gravel sizes between these values will be rounded to the closest integer and bar spacing will be decided accordingly.

According to the 40% void ratio design assumption, *n* and *m* values are shown on Table 3.3 in which d_{50} is median gravel size.

Table 3.3 *n*, bar spacing and *m*, bar distance values for different site conditions

Median Gravel Size	$d_{50} \leq 2$ **cm**	**2 cm <** $d_{50} <$ **4 cm**	$d_{50} \geq 4$ **cm**
n **(bar spacing in cm)**	2	3	4
m **(bar distance in cm)**	5	8	10
D **(bar diameter in cm)**	3	5	6

For very long trash racks, if heavy boulders are present in the bed load; even the stiffness of 6 cm diameter bars can be a problem. In that condition, perpendicular stiffening bars can be placed in the rack or diameters can be increased to overcome that issue.

After deciding on the bar type and dimensions, slope of the rack is the next criteria that affects the behavior of the system. Past studies show that, the best hydraulic performance is supplied when the rack slope is 30% (Aghamajidi and Heydari, 2014).

Also according to Drobir (1981) in the design of Tyrolean intakes, optimum rack slope is 20% to 30%.

When the slope is 30%, discharge ratio makes a peak and highest efficiency results are obtained (Kamanbedast and Bejestan, 2008).

The meaning of 30% slope is 3 vertical 10 horizontal, which means 16.7 degrees of inclination angle. In this study, bar angle is decided as 16.7 degrees while designing the intake structure.

Iterative and closed form methods are described in this chapter. These methods are used to develop the computer program to analyze Tyrolean weirs. Formulae developed in past studies are given, and assumptions and design criteria are explained which are used in the design interface of the software. Two stages of the computer program which are analysis and design interfaces will be explained in the next chapter.

CHAPTER 4

DEVELOPMENT OF COMPUTER PROGRAM

4.1 Introduction

For the analysis and design of a Tyrolean intake, a computer software named Tyrol is developed and adopted to the Visual Basic programming language. The reason for selecting Visual Basic language is the sentence-like phrase usage for developing algorithms which make the programing easier for the programmer and the reader.

In addition to its simplicity in writing, Visual Basic can supply an environment suitable for designing the software window visually in a quick and user friendly manner. Moreover, those advantages do not make it a low level program for developing engineering applications since the developer is still able to code complex formulas and the software can easily handle them within a quite short time.

Figure 4.1 Welcome screen of the program

4.2 Program Interface

The "Welcome" screen of the program is shown in Figure 4.1. When the Tyrol Software is opened, the user is asked for selecting the purpose of calculation. There are two options for that stage. When the selection is made, a new window opens according to the clicked button.

4.2.1 Design Interface

If the user clicks the "Design" button, Tyrol opens a new window developed for the design purpose (See Figure 4.2). In that window there are text boxes on a grey background for the user to enter input values. For stream information frame, these input values are median gravel size in mm, stream discharge in m3/s, channel width of the stream in m, flow depth of water in m. Below stream information frame, design discharge frame is given. User is asked to give an input value for the desired discharge to be taken into intake channel.

Solution methods described in chapter 3 are used in the Tyrol program and same procedures are applied explained in chapter 5. User chooses a method from the list, otherwise constant energy level, iterative method is randomly selected.

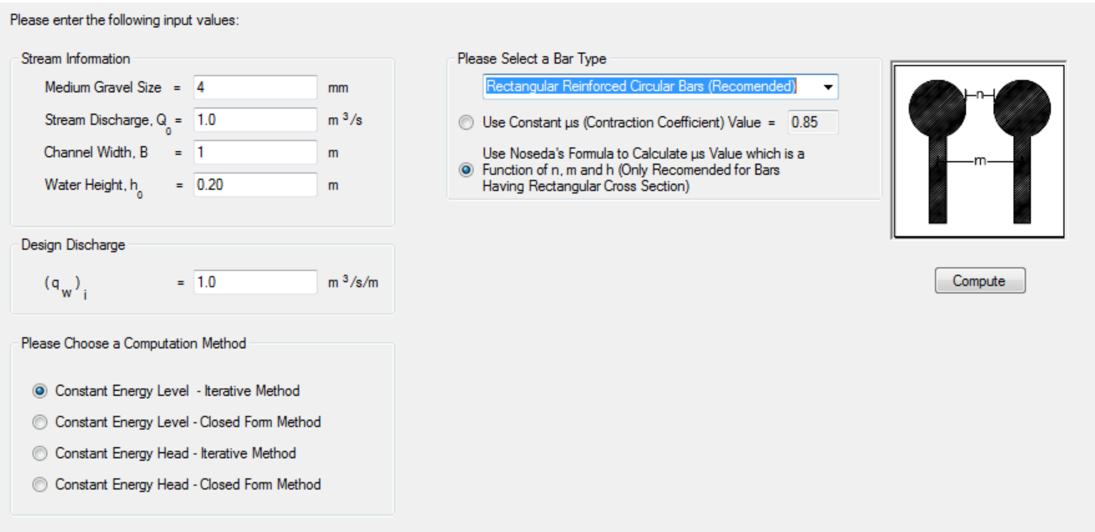


Figure 4.2 Design interface view

On the right hand side of design window, there is a frame for the bar type selection. When the dropdown list is clicked, user can select one bar type from the list. Bar types in the list are; rectangular reinforced circular bars, ovoid bars, rectangular bars and circular bars. Rectangular reinforced circular bars item is randomly selected since it is the recommended bar type.

In the same frame, user is asked to choose between two options for the calculation of contraction coefficient. Program can make calculations according to the bar type based predefined constant values or a variable depending on the bar spacing, central bar distance and flow depth.

There are some assumptions made according to the recommendations explained in Chapter 3. Median gravel size defines the bar spacing since the main idea between the bar spacing distance is to avoid the bed sediment entrance into the intake channel (See Table 3.3).

Another assumption is used to determine the central bar distance. Ratio of spacing to total rack width is assumed to be 40%. Moreover, trash rack slope is taken as 30% which needs an inclination angle of 16.7 degrees.

Finally, when the Compute button is clicked Tyrol program runs and calculates rack length according to the selected solution method and given input values.

4.2.2 Analysis Interface

Program asks user to enter the necessary input values to calculate the water surface profile and the discharge taken into the channel. Inputs are bar spacing n, central distance of bars m, trash tack inclination angle $\mathcal{E}$, trash rack length L, stream discharge Q_0, channel width B, and the water depth at the beginning of the trash rack h_1 (See Figure 4.3).

Trash rack bar type should also be selected. If no custom selection is made, program will select rectangular reinforced circular bar type as the default choice.

When the user selects a custom bar type, picture showing the cross-section of the bar changes according to the selection. As can be seen in Figure 4.3, “Rectangular Reinforced Circular Bars” option is selected and on the right hand side of the dropdown menu, cross section of the bar type is shown.

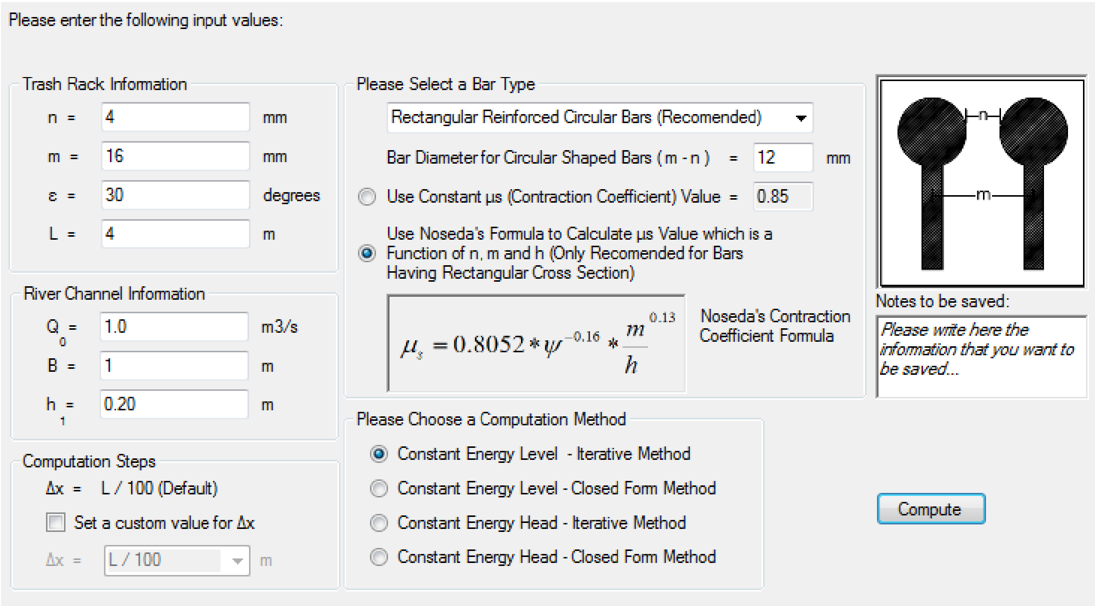


Figure 4.3 Analysis interface view

Bar type selection also affects the formulae and constants within the program algorithms. Also, contraction coefficient is to be decided; it can be calculated from the formula or predefined constant values can be used.

Then, the user selects a Δx value to decide the computation or in other terms iteration steps to be applied. L/100 is again the default selection decided for the program. User is free to select from different unit distances other than the default value that will be used in the calculation steps.

Finally, user selects one of the methods which are previously described in this study.

When the “Compute” button is clicked, then the program calculates the results according to the selected design criteria and method.

The output window creates a data table with the method's name which is selected before clicking the compute button in the first column. Then, h_1 value which is in fact the flow depth input value entered by the user is shown. Second flow depth value $h_{Release}$ is the water depth at the end of the rack bars. Finally, $q_{Channel}$ and $q_{Release}$ values represent the unit discharge taken into the channel through the screens and water released to the downstream, respectively.

	h1 (m)	h Release (m)	q Channel (m3/s/m)	q Release (m3/s/m)
Constant Energy Level - Iterative Solution	0.2	0.026	0.784	0.216
*				

Figure 4.4 Program output data table

Source code of Tyrol software is given in Appendix.

CHAPTER 5

APPLICATION

5.1 Introduction

In Chapter 3, solution methods are mentioned and formulae are given to calculate the water surface profile over the trash rack and discharge taken into the channel. To create a better understanding of the methods, two examples will be presented and solved below.

In the first example, a Tyrolean weir structure is analyzed. Solution methods described in Chapter 3 are used to calculate the discharge taken into the intake channel and to determine the water surface profile. Methods are applied according to the two basic assumptions which are shown below:

1. First Assumption: Constant Energy Level

   1.1 Iterative Method
   1.2 Closed Form Method

2. Second Assumption: Constant Energy Head

   2.1 Iterative Method
   2.2 Closed Form Method

In the second example, a Tyrolean weir structure is designed. The discharge taken into the intake channel is known. Inclination angle, diameter, spacing and length of trash rack bars are determined in the solution. Second example shows the design stage of a Tyrolean intake according to the assumptions and recommendations described in past studies which are explained in Chapters 2 and 3.

5.2 Analysis Application

In this part of the study, a Tyrolean weir is analyzed with reference to a sketch shown in Figure 5.1 using to the methods explained in Chapter 3.

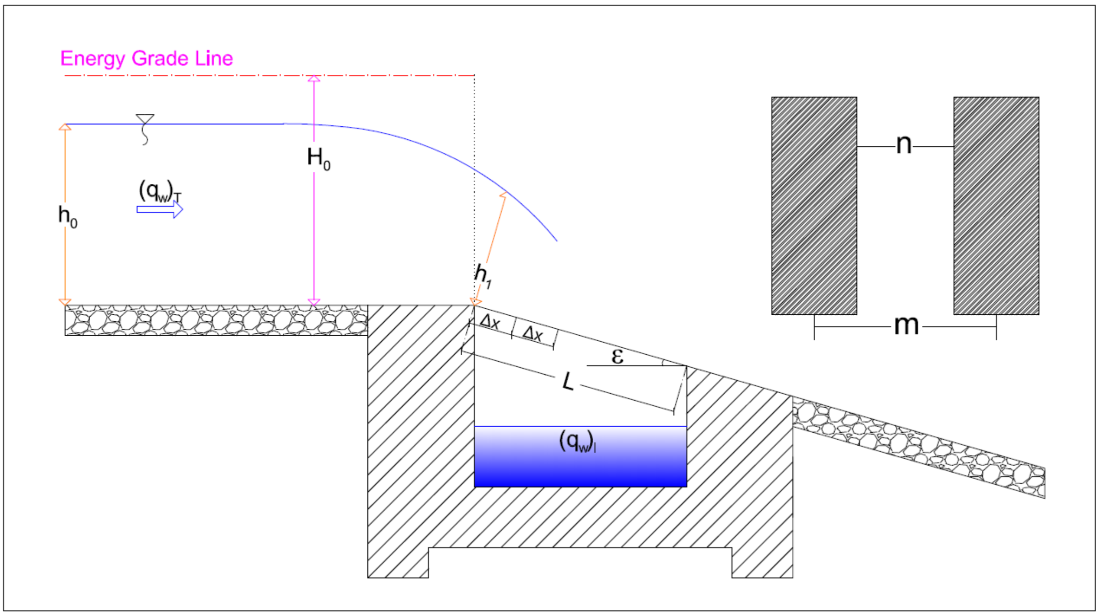


Figure 5.1 Sketch for Tyrolean weir analysis application

Total discharge $(q_w)_T$ of the Tyrolean weir shown in Figure 5.1 is 1.00 $m^3/s/m$. If the flow depth at the head of the trash rack (h_1) is 0.20 m, the length of the trash rack (L) is 4.0 m, the inclination of the trash rack $(\mathcal{E})$ is 30.0^o and m and n values of the rack bars are 4 mm and 16.0 mm, respectively, calculate the diverted discharge $(q_w)_i$ and the flow depth at the end of the trash rack.

5.2.1 The First Assumption: Constant Energy Level

5.2.1.1 Iterative Solution Method

Let's assume the Δx value as 1.0 m. So, trash rack will be analyzed in four intervals and the flow depth at the end of the trash rack will be h_5 (See Figure 5.2).

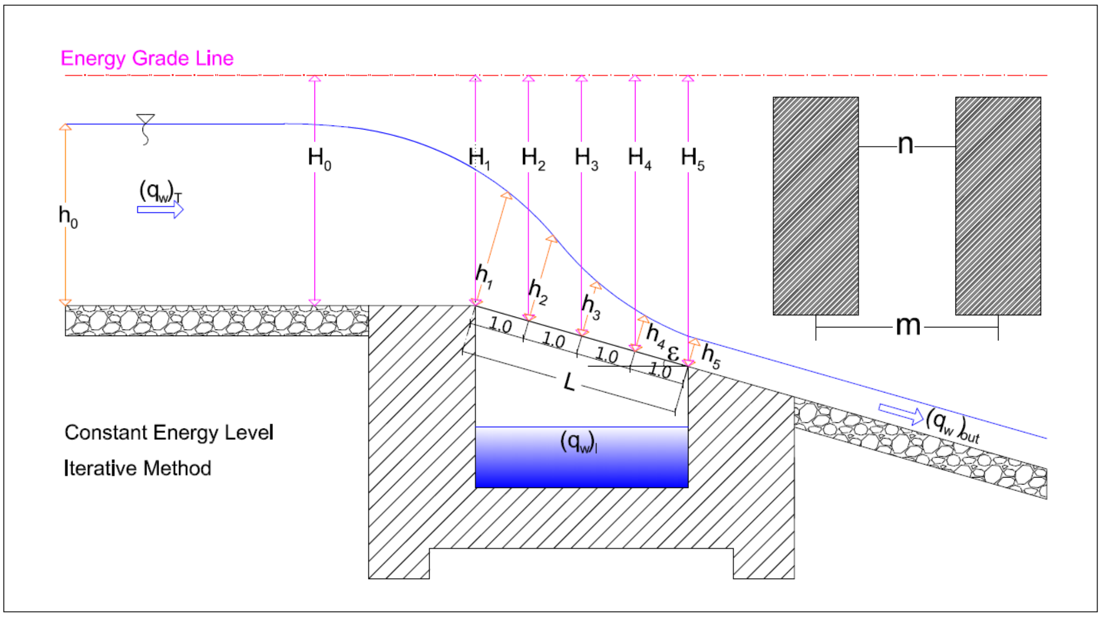


Figure 5.2 Constant energy level approach iterative solution sketch

$$(q_w)_T = h_1\sqrt{2g(H_o - h_1 \cos\varepsilon)}$$

$$1.0 = 0.20 \times \sqrt{2 \times 9.81 \times (H_o - 0.20 \times \cos 30)}$$

$$H_o = 1.447 \text{ m}$$

<u>Computation for the first interval</u>

In the first stage, the diverted discharge $(q_w)_{i1}$ in the first 0.25 m interval and the flow depth h_2 are computed.

$$(q_w)_{i.1} = \lambda\sqrt{h_{ave}}.\Delta x\ ,\ h_{ave} = \frac{h_1 + h_2}{2} \text{ and } \lambda = \psi\mu_s\sqrt{2g\cos\varepsilon}$$

$$\psi = \frac{n}{m} = \frac{4}{16} = 0.25$$

$$\mu_s = 0.66\psi^{-0.16}\left(\frac{m}{h_{ave}}\right)^{0.13} = 0.66\times 0.25^{-0.16}\times\left(\frac{0.016}{h_{ave}}\right)^{0.13} = \frac{0.481}{h_{ave}{}^{0.13}}$$

First iteration, assume $h_2=0.14$ m

$$h_{ave} = \frac{h_1 + h_2}{2} = \frac{0.20 + 0.14}{2} = 0.17 \text{ m}$$

$$\mu_s = \frac{0.54}{0.17^{0.13}} = 0.606$$

$$\lambda = 0.25\times 0.606\times\sqrt{2\times 9.81\times\cos 30} = 0.624$$

$$(q_w)_{i.1} = 0.624\times\sqrt{0.17}\times 1.00 = 0.257 \text{ m}^3/\text{s}/\text{m}$$

$$(q_w)_1 = (q_w)_T - (q_w)_{i1} = 1.00 - 0.257 = 0.743 \text{ m}^3/\text{s}/\text{m}$$

$(q_w)_1$ is the remaining discharge that moves towards downstream after the first interval. The assumption made is to be checked considering whether or not the energy level is constant.

$$(q_w)_1 = h_2\sqrt{2g(H_o + \Delta x\sin\varepsilon - h_2\cos\varepsilon)}$$

$$0.743 = h_2\sqrt{2\times 9.81\times(1.447 + 1.00\times\sin 30 - h_2\cos 30)}$$

$$h_2 = 0.124m \neq 0.14 \text{ m}$$

Second iteration, assume $h_2 = 0.124$ m

$$h_{ave} = \frac{h_1 + h_2}{2} = \frac{0.20 + 0.124}{2} = 0.162 \text{ m}$$

$$\mu_s = \frac{0.481}{0.162^{0.13}} = 0.610$$

$$\lambda = 0.25 \times 0.610 \times \sqrt{2 \times 9.81 \times \cos 30.0} = 0.628$$

$$(q_w)_{i1} = 0.628 \times \sqrt{0.162} \times 1.00 = 0.253 \text{ m}^3/\text{s}/\text{m}$$

$$(q_w)_1 = (q_w)_T - (q_w)_{i1} = 1.0 - 0.253 = 0.747 \text{ m}^3/\text{s}/\text{m}$$

$$(q_w)_1 = h_2 \sqrt{2g(H_o + \Delta x \sin\theta - h_2 \cos\theta)}$$

$$0.747 = h_2 \sqrt{2 \times 9.81 \times (1.447 + 1.00 \times \sin 30.0 - h_2 \cos 30.0)}$$

$h_2 = 0.124$ m (Assumption is converged)

So, in the first 1.00 m interval 0.253 m^3/s/m discharge is diverted and the remaining discharge $(q_w)_1$ 0.747 m^3/s/m moves towards downstream. The flow depth h_2 was verified as 0.124 m.

Computation for the second interval

First iteration, assume $h_3 = 0.08$ m,

$$h_{ave} = \frac{h_2 + h_3}{2} = \frac{0.124 + 0.08}{2} = 0.102 \text{ m}$$

$$\mu_s = \frac{0.608}{0.102^{0.13}} = 0.647$$

$$\lambda = 0.25 \times 0.647 \times \sqrt{2 \times 9.81 \times \cos 30.0} = 0.667$$

$$(q_w)_{i2} = 0.667 \times \sqrt{0.102} \times 1.00 = 0.213 \text{ m}^3/\text{s}/\text{m}$$

$$(q_w)_2 = (q_w)_1 - (q_w)_{i2} = 0.747 - 0.213 = 0.534 \text{ m}^3/\text{s}/\text{m}$$

$$(q_w)_2 = h_3\sqrt{2g(H_o + 2\Delta x \sin\theta - h_3\cos\theta)}$$

$$0.361 = h_3\sqrt{2\times 9.81\times(1.447 + 2\times 1.00\times \sin 30.0 - h_3\cos 30.0)}$$

$$h_3 = 0.078 \neq 0.080 \text{ m}$$

By assuming h_3=0.078 m, the same procedure is followed and verification is made. Final values are found as;

$$h_3 = 0.078 \text{ m}$$

$(q_w)_{i2} = 0.213$ m^3/s/m (diverted discharge in the second interval)

$(q_w)_2 = 0.535$ m^3/s/m (remaining discharge after the second interval)

Similar computations are made for each interval and the outcome is given below.

<u>Computation for the third interval</u>

$$h_4 = 0.047 \text{ m}$$

$(q_w)_{i.3}$ = 0.178 m^3/s/m (diverted discharge in the third interval)

$(q_w)_3$ = 0.357 m^3/s/m (remaining discharge after the third interval)

<u>Computation for the fourth interval</u>

$$h_5 = 0.026 \text{ m}$$

$(q_w)_{i4} = 0.145$ m^3 / s / m (diverted discharge in the fourth interval)

$(q_w)_{out} = 0.212$ m^3 / s / m (remaining discharge after the fourth interval, end of the trash rack)

So water diverted to the collection channel can be summed up,

$$(q_w)_i = (q_w)_{i1} + (q_w)_{i2} + (q_w)_{i3} + (q_w)_{i4}$$

$$(q_w)_i = 0.253 + 0.213 + 0.178 + 0.145 = 0.788 \text{ m}^3 / \text{s} / \text{m}$$

Discharge that passes over the trash rack and moves towards downstream is $(q_w)_{out}$ = 0.212 m^3 / s / m

Flow depth at the end of the trash rack $h_5 = 0.026$ m

Given values, assumptions, and calculated results are shown in Tables 5.1 - 5.3.

Table 5.1 Constant Energy Level – Iterative Solution Method, Given, calculated and assumed values

Given values

$(q_w)_T$ (m^3/s/m)	L (m)	ε (degree)	ε (radians)	h_1 (m)	n (mm)	m (mm)
1.000	4.000	30.000	0.524	0.200	4.000	16.000

Calculated & Assumed Values

H_0 (m)	Δx (m)	ψ	$\mu_s * h_{ave}^{0.13}$	g (m/s^2)
1.447	1.000	0.250	0.481	9.810

Table 5.2 Constant Energy Level – Iterative Solution Method, First Three Intervals

Interval: 1

1st Iteration Values (Assume h_2 = 0.14)

h_2 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.1}$ (m^3/s/m)	$(q_w)_1$ (m^3/s/m)	h_2 (m) (Check)
0.140	0.170	0.606	0.624	0.257	0.743	0.124

2nd Iteration Values (Assume h_2 = 0.124)

h_2 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.1}$ (m^3/s/m)	$(q_w)_1$ (m^3/s/m)	h_2 (m) (Check)
0.124	0.162	0.610	0.628	0.253	0.747	0.124

Interval: 2

1st Iteration Values (Assume h_2 = 0.080)

h_3 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.2}$ (m^3/s/m)	$(q_w)_2$ (m^3/s/m)	h_3 (m) (Check)
0.080	0.102	0.647	0.667	0.213	0.534	0.078

2nd Iteration Values (Assume h_2 = 0.078)

h_3 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.2}$ (m^3/s/m)	$(q_w)_2$ (m^3/s/m)	h_3 (m) (Check)
0.078	0.101	0.648	0.668	0.213	0.535	0.078

Interval: 3

1st Iteration Values (Assume h_2 = 0.050)

h_4 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.3}$ (m^3/s/m)	$(q_w)_3$ (m^3/s/m)	h_4 (m) (Check)
0.050	0.064	0.688	0.709	0.180	0.355	0.047

2nd Iteration Values (Assume h_2 = 0.047)

h_4 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.3}$ (m^3/s/m)	$(q_w)_3$ (m^3/s/m)	h_4 (m) (Check)
0.047	0.063	0.690	0.711	0.178	0.357	0.047

Table 5.3 Constant Energy Level – Iterative Solution Method, Fourth Interval and Results

Interval: 4

1st Iteration Values (Assume h_2 = 0.040)

h_5 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.4}$ (m^3/s/m)	$(q_w)_4$ (m^3/s/m)	h_5 (m) (Check)
0.040	0.044	0.723	0.745	0.156	0.201	0.025

2nd Iteration Values (Assume h_2 = 0.025)

h_5 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.4}$ (m^3/s/m)	$(q_w)_4$ (m^3/s/m)	h_5 (m) (Check)
0.025	0.036	0.742	0.764	0.145	0.212	0.026

Water diverted to the collection channel is:

$(q_w)_{i.1}$ = 0.253 m^3/s/m

$(q_w)_{i.2}$ = 0.213 m^3/s/m

$(q_w)_{i.3}$ = 0.178 m^3/s/m

$(q_w)_{i.4}$ = 0.145 m^3/s/m

$(q_w)_i$ = **0.788** **m^3/s/m**

Discharge that passes over the trash rack and moves towards downstream is:

$(q_w)_{out}$ = **0.212** **m^3/s/m**

Flow depth at the end of the trash rack is:

h_5 = **0.026** **m**

5.2.1.2 Closed Form Solution

$(q_w)_T = 1.0\, m^3/s\,/m$ and $h_1 = 0.20$ m

$$\lambda = \psi \mu_s \sqrt{2g\cos\theta}\,,\ \psi = \frac{n}{m} = \frac{4}{16} = 0.25$$

$$\mu_s = 0.66\psi^{-0.16}\left(\frac{m}{h_1}\right)^{0.13} = 0.66\times 0.25^{-0.16}\times\left(\frac{0.016}{0.20}\right)^{0.13} = 0.593$$

$$\lambda = 0.25\times 0.593\times.\sqrt{2\times 9.81\times\cos 30.0} = 0.611$$

Flow length over the trash rack is computed as

$$L = 2.561\frac{(q_w)_T}{\lambda\sqrt{h_1}} = 2.561\frac{1.00}{0.611\sqrt{0.20}} = 9.366\ m > 4\text{ m}$$

It is seen that, some portion of the incoming discharge is diverted to the collection channel while the remaining discharge flows towards downstream. To determine the diverted discharge $(q_w)_i$, the depth at the end of trash rack h_2 is to be calculated.

$$\frac{s^2}{L^2} = 2\frac{h_2}{h_1} - \frac{h_2^{\ 2}}{h_1^{\ 2}},\ \text{s} = 9.366 - 4 = 5.366\ \text{ m}$$

$$\frac{5.366^2}{9.366^2} = 2\frac{h_2}{0.20} - \frac{h_2^{\ 2}}{0.20^2},\ h_2 = 0.036\text{ m}$$

After completing calculation of h_2

$$(q_w)_i = 1.707(q_w)_T\left[2-\left(1+\frac{h_2}{h_1}\right)\left(\sqrt{2-\frac{h_2}{h_1}}\right)\right]$$

$$(q_w)_i = 1.707(q_w)_T\left[2-\left(1+\frac{0.036}{0.20}\right)\left(\sqrt{2-\frac{0.036}{0.20}}\right)\right]$$

$(q_w)_i$ = 0.698 m^3 / s / m

$(q_w)_T$ = 0.304 m^3 / s / m

In Table 5.4, given values and results are shown for Constant Energy Level, Closed Form Method

Table 5.4 Constant Energy Level – Closed Form Method, Given Values and Results

Given values

$(q_w)_T$ (m^3/s/m)	L (m)	$\mathcal{E}$ (degree)	$\mathcal{E}$ (radians)	h_1 (m)	n (mm)	m (mm)	
1.000	4.000	30.000	0.524	0.200	4.000	16.000	

Calculated and Assumed Values

H_0 (m)	Δx (m)	ψ	μ_s	λ	g (m/s^2)	L	
1.447	1.000	0.250	0.593	0.611	9.810	9.366	$> L$

s	h_2 (m)
5.366	0.036

$(q_w)_i$ = **0.696 m^3/s/m**

$(q_w)_{out}$ = **0.304 m^3/s/m**

5.2.2 The Second Assumption: Constant Energy Head

5.2.2.1 Iterative Solution

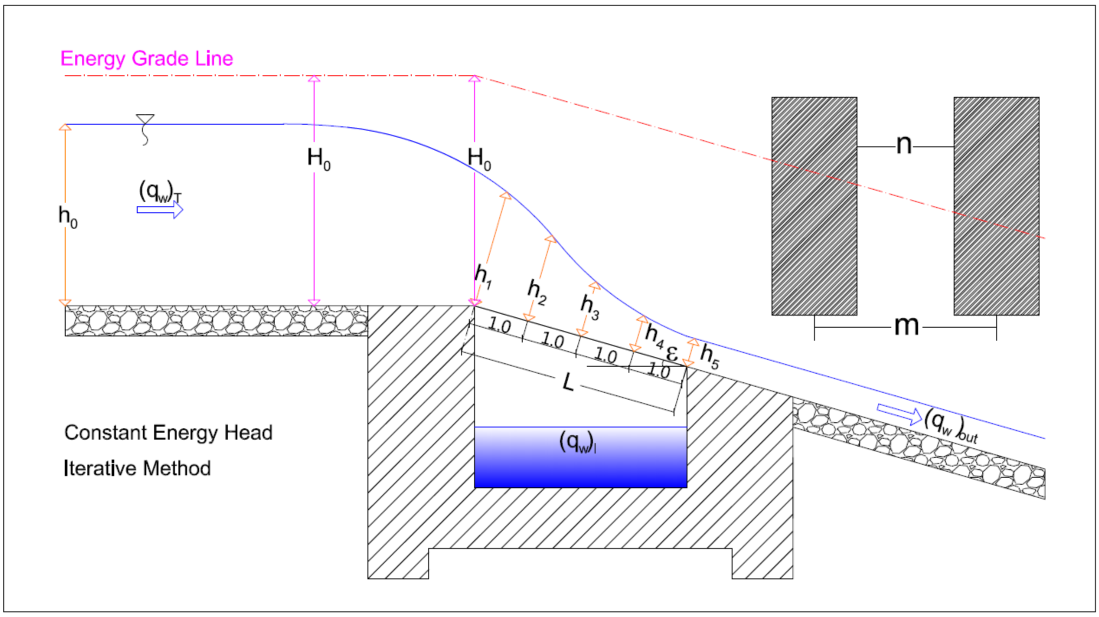


Figure 5.3 Constant energy head approach iterative solution sketch

In iterative solution, the depth of the flow in each interval must be computed to determine the flow condition. Calculations are made in two stages. In the first stage, the flow depths and in the second stage, the discharge that passes over each interval will be calculated.

<u>Calculation of h_2</u>

$$\Delta x = \frac{H_0}{\mu_s \psi}\left[\phi\left(\frac{h_2}{H_0}\right) - \phi\left(\frac{h_1}{H_0}\right)\right]$$

$$\mu_s = 0.66\psi^{-0.16}\left(\frac{m}{h_1}\right)^{0.13} = 0.66 \times 0.25^{-0.16} \times \left(\frac{0.016}{0.20}\right)^{0.13} = 0.593$$

$H_o = 1.447m$, $h_1 = 0.20m$, $\psi = \frac{n}{m} = \frac{4}{16} = 0.25$

$$1.00 = \frac{1.447}{0.593 \times 0.25}\left[\phi\left(\frac{h_2}{1.447}\right) - \phi\left(\frac{0.20}{1.447}\right)\right]$$

ϕ function can be solved by using the Equation (3.21) or with the help of Table 3.1.

$$\phi\left(\frac{0.20}{1.447}\right) = \frac{1}{2} \times \arccos\sqrt{\frac{0.20}{1.447}} - \frac{3}{2} \times \sqrt{\frac{0.20}{1.447} \times \left(1 - \frac{0.20}{1.447}\right)} = 0.077$$

$\phi\left(\frac{h_2}{0.49}\right) = 0.180$, by matching Table 3.1 or iterating from equations; $h_2 = 0.142$ m

Calculation of h_3

$$\Delta x = \frac{H_0}{\mu_s \psi}\left[\phi\left(\frac{h_3}{H_0}\right) - \phi\left(\frac{h_2}{H_0}\right)\right]$$

$$1.00 = \frac{1.447}{0.593 \times 0.25}\left[\phi\left(\frac{h_3}{1.447}\right) - \phi\left(\frac{0.142}{1.447}\right)\right], \ \phi\left(\frac{0.142}{1.447}\right) = 0.180$$

$\phi\left(\frac{h_3}{0.49}\right) = 0.282$, $h_3 = 0.096$ m

Calculation of h_4

$$\Delta x = \frac{H_0}{\mu_s \psi}\left[\phi\left(\frac{h_4}{H_0}\right) - \phi\left(\frac{h_3}{H_0}\right)\right]$$

$$1.00 = \frac{0.49}{0.593 \times 0.25}\left[\phi\left(\frac{h_4}{1.447}\right) - \phi\left(\frac{0.096}{1.447}\right)\right],\ \phi\left(\frac{0.096}{1.447}\right) = 0.282$$

$$\phi\left(1\frac{h_4}{0.447}\right) = 0.385,\ h_4 = 0.060 \text{ m}$$

<u>Calculation of h_5</u>

$$\Delta x = \frac{H_0}{\mu_s \psi}\left[\phi\left(\frac{h_5}{H_0}\right) - \phi\left(\frac{h_4}{H_0}\right)\right]$$

$$1.00 = \frac{1.447}{0.593 \times 0.25}\left[\phi\left(\frac{h_5}{1.447}\right) - \phi\left(\frac{0.060}{1.447}\right)\right],\ \phi\left(\frac{0.060}{0.49}\right) = 0.385$$

$$\phi\left(\frac{h_5}{1.447}\right) = 0.487,\ h_5 = 0.033 \text{ m}$$

Flow depths (h_1, h_2, h_3, h_4, h_5) are calculated.

In the second step the discharges will be calculated and the flow depth found in the first step will be used to check the flow condition.

<u>Calculation of q_2</u>

$$\Delta x = \frac{H_0}{\mu_s \psi}\left[\beta\left(\frac{q_2}{q_{\max}}\right) - \beta\left(\frac{q_1}{q_{\max}}\right)\right]$$

$$q_{max} = 1.705\ x\ H_0^{3/2} = 1.705\ x\ 1.447^{3/2} = 2.969\ \text{m}^3 / \text{s} / \text{m}$$

β function can be solved by using the Equation (3.21) or with the help of Table 3.1. But to solve β function, first the flow condition must be determined.

$$h_{cr} = \sqrt[3]{\frac{q_1^{\ 2}}{g}} = \sqrt[3]{\frac{1.0^2}{9.81}} = 0.467 \text{ m}$$

$$h_{cr} = \sqrt[3]{\frac{q_1^2}{g}} = \sqrt[3]{\frac{1.0^2}{9.81}} = 0.467 \text{ m}$$

$h_{cr} > h_1 = 0.20\ m$, flow is supercritical.

$$\beta\left(\frac{q_1}{q_{\max}}\right) = \frac{1}{2} \times \arccos\left(\frac{1}{\sqrt{3}} \times \sqrt{2\cos\varphi + 1}\right) - \frac{\sqrt{2}}{2} \times \sqrt{(2\cos\varphi + 1) \times (1 - \cos\varphi)}$$

$$\varphi = \frac{1}{3} \times \arccos\left(1 - 2 \times \left(\frac{1.0}{2.969}\right)^2\right) + 240^o = 253.122^o$$

$\beta\left(\frac{q_1}{q_{\max}}\right) = 0.074$, $\beta\left(\frac{q_2}{q_{\max}}\right) = 0.176$, by matching Table 3.1 or iterating from Equation (3.21).

$q_2 = 0.727 \text{ m}^3 / \text{s} / \text{m}$

<u>Calculation of q_3</u>

$$\Delta x = \frac{H_0}{\mu_s \psi}\left[\beta\left(\frac{q_3}{q_{\max}}\right) - \beta\left(\frac{q_2}{q_{\max}}\right)\right]$$

$$h_{cr} = \sqrt[3]{\frac{q_2^2}{g}} = \sqrt[3]{\frac{0.727^2}{9.81}} = 0.378 \text{ m}$$

$h_{cr} > h_2 = 0.142\ m$, flow is supercritical.

$$\varphi = \frac{1}{3} \times \arccos\left(1 - 2 \times \left(\frac{0.727}{2.969}\right)^2\right) + 240^o = 249.445^o$$

$\beta\left(\frac{q_2}{q_{max}}\right) = 0.177$, $\beta\left(\frac{q_3}{q_{max}}\right) = 0.279$, by matching Table 3.1 or iterating from equations.

$q_3 = 0.500\ \text{m}^3/\text{s}/\text{m}$

Calculation of q_4

$$\Delta x = \frac{H_0}{\mu_s \psi}\left[\beta\left(\frac{q_4}{q_{max}}\right) - \beta\left(\frac{q_3}{q_{max}}\right)\right]$$

$$h_{cr} = \sqrt[3]{\frac{q_3^2}{g}} = \sqrt[3]{\frac{0.500^2}{9.81}} = 0.294\ \text{m}$$

$h_{cr} > h_3 = 0.096\ m$, flow is supercritical.

$$\varphi = \frac{1}{3} \times \arccos\left(1 - 2 \times \left(\frac{0.500}{2.969}\right)^2\right) + 240^o = 246.464^o$$

$\beta\left(\frac{q_3}{q_{max}}\right) = 0.279$, $\beta\left(\frac{q_4}{q_{max}}\right) = 0.382$, by matching Table 3.1 or iterating from equations.

$q_4 = 0.316\ \text{m}^3/\text{s}/\text{m}$

Calculation of q_5

$$\Delta x = \frac{H_0}{\mu_s \psi}\left[\beta\left(\frac{q_5}{q_{max}}\right) - \beta\left(\frac{q_4}{q_{max}}\right)\right]$$

$$h_{cr} = \sqrt[3]{\frac{q_4^2}{g}} = \sqrt[3]{\frac{0.316^2}{9.81}} = 0.217\ m$$

$h_{cr} > h_4 = 0.060\ m$, flow is supercritical.

$$\varphi = \frac{1}{3} \times \arccos\left(1 - 2 \times \left(\frac{0.316}{2.969}\right)^2\right) + 240^o = 244.071^o$$

$\beta\left(\frac{q_4}{q_{max}}\right) = 0.382,\quad \beta\left(\frac{q_5}{q_{max}}\right) = 0.485,$ by matching Table 3.1 or iterating from equations.

$q_5 = 0.175\ \text{m}^3/\text{s}/\text{m}$

q_5 is the amount of discharge that passes over the trash rack and moves towards downstream. By subtracting q_5 from the total discharge, the diverted discharge $(q_w)_i$ can be calculated.

$(q_w)_i = (q_w)_T - q_5 = 1.0 - 0.175 = 0.825\ \text{m}^3/\text{s}/\text{m}$

Given values and results are shown step by step in Tables 5.5 – 5.8.

Table 5.5 Constant Energy Head – Iterative Solution Method, First Part (Using h_1 in μ_s Formula - μ_s Constant)

Given values

$(q_w)_T$ (m^3/s/m)	L (m)	ε (radians)	h_1 (m)	n (mm)	m (mm)	g (m/s^2)
1.000	4.000	0.524	0.200	4.000	16.000	9.810

Calculation of h_2

H_0 (m)	Δx (m)	ψ	μ_s	φ (h_1/H_0)	φ (h_2/H_0)	h_2 (m)
1.447	1.000	0.250	0.593	0.077	0.180	0.142

Calculation of h_3

φ (h_3/H_0)	h_3 (m)
0.282	0.096

Calculation of h_4

φ (h_4/H_0)	h_4 (m)
0.385	0.060

Calculation of h_5

φ (h_5/H_0)	h_5 (m)
0.487	0.033

Calculation of q_2

q_{max} (m^3/s/m)	h_{cr} (m)	
2.969	0.467	> h2 , Supercritical

ϕ (degree)	ϕ (radians)	β_1	β_2	ϕ (degree)	ϕ (radians)	$(q_w)_2$ (m^3/s/m)
253.122	4.418	0.074	0.176	249.445	4.354	0.727

Table 5.6 Constant Energy Head – Iterative Solution Method, Second Part (Using h_1 in μ_s Formula - μ_s Constant)

Calculation of q_3

q_{max} ($m^3/s/m$)	h_{cr} (m)	
2.969	0.378	> h2 , Supercritical

ϕ (degree)	ϕ (radians)	β_2	β_3	ϕ (degree)	ϕ (radians)	$(q_w)_3$ ($m^3/s/m$)
249.445	4.354	0.177	0.279	246.464	4.302	0.500

Calculation of q_4

q_{max} ($m^3/s/m$)	h_{cr} (m)	
2.969	0.294	> h2 , Supercritical

ϕ (degree)	ϕ (radians)	β_3	β_4	ϕ (degree)	ϕ (radians)	$(q_w)_4$ ($m^3/s/m$)
246.464	4.302	0.279	0.382	244.071	4.260	0.316

Calculation of q_5

q_{max} ($m^3/s/m$)	h_{cr} (m)	
2.969	0.217	> h2 , Supercritical

ϕ (degree)	ϕ (radians)	β_4	β_5	ϕ (degree)	ϕ (radians)	$(q_w)_5$ ($m^3/s/m$)
244.071	4.260	0.382	0.485	242.249	4.228	0.175

$(q_w)_i$ = 0.825 $m^3/s/m$

$(q_w)_{out}$ = 0.175 $m^3/s/m$

μ_s is obtained by using h_1 to make steps easier in hand calculation. However, to get better results μ_s can be calculated by using h_{ave} rather than h_1.

$$\mu_s = 0.66\psi^{-0.16}\left(\frac{m}{h_{ave}}\right)^{0.13} = 0.66\times 0.25^{-0.16}\times\left(\frac{0.016}{h_{ave}}\right)^{0.13} = \frac{0.481}{h_{ave}{}^{0.13}}$$

In Table 5.7, Calculations made by using h_{ave} in μ_s formula are shown.

Table 5.7 Constant Energy Head – Iterative Solution Method, (Using h_{ave} in μ_s Formula - μ_s Not Constant)

Given values

$(q_w)_T$ (m^3/s/m)	L (m)	ε (radians)	h_1 (m)	n (mm)	m (mm)	H_0 (m)
1.000	4.000	0.524	0.200	4.000	16.000	1.447

Calculation of h_2

Δx (m)	ψ	h_{ave} (m)	μ_s	φ (h_1/H_0)	φ (h_2/H_0)	h_2 (m)
1.000	0.250	0.170	0.606	0.077	0.182	0.141

Calculation of h_3

h_{ave} (m)	μ_s	φ (h_3/H_0)	h_3 (m)
0.116	0.637	0.292	0.092

Calculation of h_4

h_{ave} (m)	μ_s	φ (h_4/H_0)	h_4 (m)
0.072	0.677	0.409	0.052

Calculation of h_5

h_{ave} (m)	μ_s	φ (h_5/H_0)	h_5 (m)
0.038	0.737	0.536	0.023

Table 5.8 Constant Energy Head – Iterative Solution Method, (Using h_{ave} in μ_s Formula - μ_s Not Constant)

Calculation of q_2

q_{max} ($m^3/s/m$)	h_{cr} (m)	
2.969	0.467	> h1 , Supercritical

ϕ (degree)	ϕ (radians)	β_1	β_2	ϕ (degree)	ϕ (radians)	$(q_w)_2$ ($m^3/s/m$)
253.122	4.418	0.074	0.178	249.401	4.353	0.723

Calculation of q_3

q_{max} ($m^3/s/m$)	h_{cr} (m)	
2.969	0.376	> h2 , Supercritical

ϕ (degree)	ϕ (radians)	β_2	β_3	ϕ (degree)	ϕ (radians)	$(q_w)_3$ ($m^3/s/m$)
249.401	4.353	0.178	0.288	246.232	4.298	0.482

Calculation of q_4

q_{max} ($m^3/s/m$)	h_{cr} (m)	
2.969	0.287	> h3 , Supercritical

ϕ (degree)	ϕ (radians)	β_3	β_4	ϕ (degree)	ϕ (radians)	$(q_w)_4$ ($m^3/s/m$)
246.232	4.298	0.288	0.405	243.611	4.252	0.280

Calculation of q_5

q_{max} ($m^3/s/m$)	h_{cr} (m)	
2.969	0.200	> h4 , Supercritical

ϕ (degree)	ϕ (radians)	β_4	β_5	ϕ (degree)	ϕ (radians)	$(q_w)_5$ ($m^3/s/m$)
243.611	4.252	0.405	0.533	241.586	4.216	0.123

$(q_w)_i$ = **0.877** **$m^3/s/m$**

$(q_w)_{out}$ = **0.123** **$m^3/s/m$**

5.2.2.2 Closed Form Solution

First, C_d is calculated by the given formula for rectangular bars:

$$C_d = 0.1296\left(\frac{t}{n}\right) - 0.4284 * S_L^2 + 0.1764$$

$$C_d = 0.1296\left(\frac{12}{4}\right) - 0.4284 * 0.577^2 + 0.1764$$

$$C_d = 0.422$$

Distance x is calculated to check if the flow is directly transferred to the channel or not.

$$\frac{x}{H_0} = \frac{1}{C_d \psi}\left(\frac{h_1}{H_0}\sqrt{1-\frac{h_1}{H_0}} - \frac{h}{H_0}\sqrt{1-\frac{h}{H_0}}\right)$$

$$(q_w)_{out} = h_2\sqrt{2g(H_0 - h_2)}$$

So the first assumption is h=0, to find if the calculated x value is within the trash rack length.

$$\frac{x}{0.49} = \frac{1}{0.422 \times 0.250}\left(\frac{0.20}{1.447}\sqrt{1-\frac{0.20}{1.447}} - \frac{0}{0.49}\sqrt{1-\frac{0}{1.447}}\right)$$

x=1.758 m

The flow length over the trash rack is 1.758 m and all incoming discharge is diverted into the collection channel.

$(q_w)i = 1.00$ m^3 / s / m

Results obtained from the application of this method are shown in Table 5.9.

Table 5.9 Constant Energy Head – Closed Form Solution Method,

Given values

$(q_w)_T$ (m^3/s/m)	L (m)	ε (degree)	ε (radians)	h_1 (m)	n (mm)	m (mm)	g (m/s^2)
1.000	4.000	30.000	0.524	0.200	4.000	16.000	9.810

H_0 (m)	Δx (m)	ψ	μ_s
1.447	1.000	0.250	0.593

h_{cr} (m)	S_L	t (mm)	C_d	x	
0.467	0.577	12.000	0.422	1.758	< L All flow is diverted to the channel

$(q_w)_{out}$ (m^3/s/m)	h_2 (m)
0.000	0.000

$(q_w)_i$ = 1.000 m^3/s/m

$(q_w)_{out}$ = 0.000 m^3/s/m

Discharge taken into the channel, discharge passing over the trash rack to the downstream and the flow depth at the end of the rack are given in Table 5.10 with respect to the method used in calculation.

Table 5.10 Comparison of Results – Analysis Application

	h (m)	$(q_w)_i$ (m^3/s/m)	$(q_w)_{out}$ (m^3/s/m)
Constant Energy Level			
Iterative Solution Method	0.026	0.788	0.212
Closed Form Solution Method	0.036	0.696	0.304
Constant Energy Head			
Iterative Solution Method	0.023	0.877	0.123
Closed Form Solution Method	0.000	1.000	0.000

5.3 Design Application

In this part of the study, a Tyrolean weir is designed according to the methods and assumptions shown in chapters 2 and 3. An example is solved below for better understanding of the design procedures. A definition sketch characterizing the design is shown in Figure 5.4.

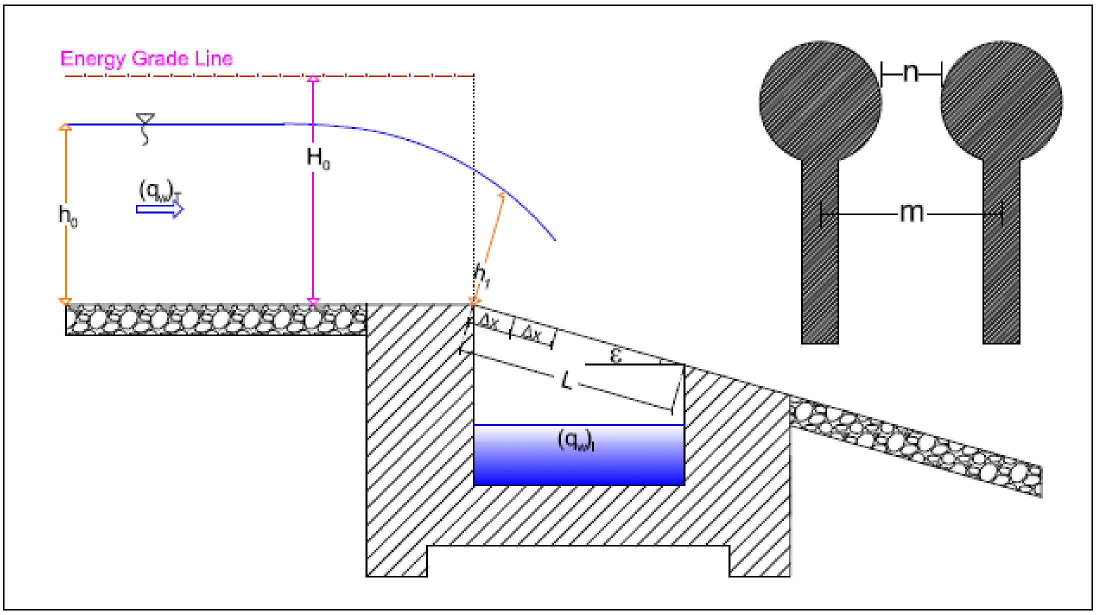


Figure 5.4 Sketch for Tyrolean weir design example

Total discharge $(q_w)_T$ of the Tyrolean weir shown in Figure 5.4 is 1.00 $m^3/s/m$. If the flow depth at the upstream of the trash rack (h_0) is 0.50 m, find the required length of the trash rack (L) to divert the design discharge into the intake channel of the structure. The design discharge is 0.80 $m^3/s/m$ and the median gravel size of the stream is 40 mm.

To begin with, some assumptions should be made according to the recommendations. First, bar type is selected as rectangular reinforced circular bar as the most efficient cross section which is shown on the right hand side of Figure 5.4. It is recommended by researchers according to the various experiments and studies mentioned in Chapter 3.

Moreover, according to past studies described in Chapter 3; n, the clear spacing between bars is selected same as the median gravel size of the stream bed sediment and m, the central distance of bars are calculated in a way that to obtain the 40% recommended void ratio. In addition to that, slope of the rack is selected as 30%, which means an inclination angle of 16.7 degrees as being recommended as the most efficient slope.

5.3.1 The First Assumption: Constant Energy Level

5.3.1.1 Iterative Solution Method:

Iterative solution method is applied twice for the design stage. At the first application, stream discharge is assumed to be equal to the design discharge to calculate the required rack length which is long enough to divert the total flow. Then in the second stage, stream discharge is taken as it is and discharge taken into the intake channel is calculated by using the rack length value obtained in the first stage. If the design discharge is supplied and water given to the downstream of the structure is appropriate for the protection of the environment, results are decided to be suitable for design. Input values to be used in the application are summarized in Table 5.11.

Table 5.11 Given input values for the design application

$(q_w)_T$ (m^3/s/m)	$(q_w)_i$ (m^3/s/m)	h_0 (m)	**Median Gravel Size** (mm)	g (m/s^2)
1.000	0.8	0.500	40.000	9.810

Assumed and calculated values for other necessary input values are shown below in Table 5.12 in which, $\mathcal{E}$ = inclination angle of the rack, n = clear spacing between bars, m = central distance of bars, D = diameter of bars, S_L = rack slope, Δx = calculation interval, ψ = n/m void ratio, H_0 = head at the upstream of the rack, h_{cr} = critical flow depth, χ = correction factor described in Equation (3.42), h_1 = flow depth at the beginning of the rack which is equal to critical flow depth h_{cr} multiplied by the correction factor χ. Values used in

Table 5.12 Calculated and assumed input values for the design application

$\mathcal{E}$ (degree)	$\mathcal{E}$ (radians)	***n*** (mm)	***m*** (mm)
16.700	0.291	40.000	100.000
Δx (m)	***D*** (mm)	S_L	ψ
0.500	60.000	0.300	0.400
H_0 (m)	h_{cr} (m)	χ	h_1 (m)
0.604	0.403	0.861	0.346

To calculate the rack length, methods suggested in Chapter 3 and their results are shown in Table 5.13.

Table 5.13 Rack length results with respect to the researcher and assumption

Rack Length according to the Frank (1956)

μ_s	λ	***L*** (m)
0.650	1.127	3.087

Rack Length according to the Noseda (1956)

μ_s	***L*** (m)
0.650	2.254

Rack Length according to the Mostkow (1957)

Calculated C_d value		Constant C_d value	
C_d	***L*** (m)	C_d	***L*** (m)
0.339	1.791	0.500	1.214

Rack Length according to the Brunella et al. (2003)

Calculated C_d value		Constant C_d value	
C_d	***L*** (m)	C_d	***L*** (m)
0.339	3.696	1.100	1.139

In the first one of the four different methods, Frank's approach is applied according to Equation (3.12). In the second one, the formula proposed by Noseda (1956) is used as shown in Equation (3.43). In the third approach, Equation (3.44) given by Mostkow (1957) is applied and in the last one, the method given by Brunella et al. (2003) is used. In the third and fourth approaches, the discharge coefficient value C_d is used. Mostkow (1957) suggested that C_d varies from 0.435, for a sloping rack 1 in 5, to 0.497 for a horizontal rack. Furthermore, Brunella et al. (2003) recommended that C_d is equal to 1.1 for porosity values, $\Psi = 0.35$ and $C_d = 0.87$ for $\Psi = 0.664$. Rack length is calculated in two different ways for Mostkow (1957) and Brunella et al. (2003). The first one is calculated by assumed discharge coefficients recommended by the related researcher and the second one is obtained by using the C_d values calculated from the formulae shown in Equation (3.25) and Equation (3.26).

Table 5.12 shows that there are many ways to calculate rack length and obtained results are quite different from each other. Although, formula given by Mostkow (1957) and Brunella et al. (2003) are approved by Jiménes and Vargas (2006), to give logical results, none of the methods are reliable enough to decide on the length of rack bars to divert the required design discharge from the stream in the present stage. So, four approaches described and used in analysis section will also be used in the design stage to get more consistent results. Selection of an appropriate value for L is recommended to be case sensitive considering local site characteristics. Therefore, final decision on L value is to be given by the designer.

Δx interval is decided as 0.5 m which seems to be logical according to the rack length values shown in Table 5.12. Calculation procedure is the same as the steps described in the analysis application. An assumption is made for the flow depth and for the first interval and the same procedure in the analysis stage is applied to calculate the discharge taken into the intake channel. When the assumed flow depth is obtained, iteration stops and calculations for the next interval starts. Results obtained from the first interval are shown in the Table 5.14 below.

Table 5.14 First stage for the design application, first interval

Interval:	**1**					
1st Iteration Values -Assume h_2 =			0.150			
h_2 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.1}$ (m^3/s/m)	$(q_w)_1$ (m^3/s/m)	h_2 (m) (Check)
0.150	0.248	0.679	1.177	0.293	0.507	0.147
2nd Iteration Values						
h_2 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.1}$ (m^3/s/m)	$(q_w)_1$ (m^3/s/m)	h_2 (m) (Check)
0.147	0.247	0.680	1.178	0.293	0.507	0.147

When the flow depth is approximately zero, rack length is said to be long enough to take the whole discharge into the weir. In Table 5.15, h_3 is calculated.

Table 5.15 First stage for the design application, second interval

Interval:	**2**					
1st Iteration Values -Assume h_3 =			0.070			
h_3 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.2}$ (m^3/s/m)	$(q_w)_2$ (m^3/s/m)	h_3 (m) (Check)
0.070	0.108	0.756	1.311	0.216	0.291	0.072
2nd Iteration Values						
h_3 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.2}$ (m^3/s/m)	$(q_w)_2$ (m^3/s/m)	h_3 (m) (Check)
0.072	0.110	0.755	1.309	0.217	0.291	0.073

Flow depth h_3 is still not close to zero. So that means rack length should be longer than the summation of two interval lengths which is 1 m. So, calculations are proceeded with the third interval which is shown in Table 5.16.

Table 5.16 First stage for the design application, third interval

Interval: 3

1st Iteration Values -Assume h_4 = 0.030

h_4 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.3}$ (m³/s/m)	$(q_w)_3$ (m³/s/m)	h_4 (m) (Check)
0.030	0.051	0.833	1.445	0.164	0.127	0.029

2nd Iteration Values

h_4 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.3}$ (m³/s/m)	$(q_w)_3$ (m³/s/m)	h_4 (m) (Check)
0.029	0.051	0.835	1.448	0.163	0.128	0.029

Flow depth becomes close to zero but not enough to stop the calculations. So, one more interval is checked which is shown in Table 5.17.

Table 5.17 First stage for the design application, fourth interval

Interval: 4

1st Iteration Values -Assume h_5 = 0.005

h_5 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.4}$ (m³/s/m)	$(q_w)_4$ (m³/s/m)	h_5 (m) (Check)
0.005	0.017	0.963	1.670	0.109	0.019	0.004

2nd Iteration Values

h_5 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.4}$ (m³/s/m)	$(q_w)_4$ (m³/s/m)	h_5 (m) (Check)
0.004	0.016	0.967	1.677	0.107	0.020	0.004

Finally, flow depth is 4 mm which is almost zero. Four 0.5 m long intervals are analyzed, so the total rack length is 2 m. The discharge taken into the intake channel is calculated by summing up the unit discharge values found in four different intervals. The results are shown in Table 5.18.

Table 5.18 First stage for the design application, discharge diverted to the intake channel

$(q_w)_{i.1}$ =	0.293	$m^3/s/m$
$(q_w)_{i.2}$ =	0.217	$m^3/s/m$
$(q_w)_{i.3}$ =	0.163	$m^3/s/m$
$(q_w)_{i.4}$ =	0.107	$m^3/s/m$
$(q_w)_i$ =	**0.780**	$\mathbf{m^3/s/m}$

Discharge that passes over the trash rack and moves towards downstream is:

$(q_w)_{out}$ = **0.020** $\mathbf{m^3/s/m}$

Flow depth at the end of the trash rack is:

h_5 = **0.004 m**

In order to take the desired discharge, which is 0.80 $m^3/s/m$, the rack length seems to be longer than 2 m according to the calculations. However, in this stage we disregard that small amount and assume 2 m long trash rack is enough. So, now in the second stage the structure is analyzed for the real discharge value for the 2 m rack length value. The results are shown in the Table 5.19 and Table 5.20.

Table 5.19 Second stage for the design application, first interval

Interval: 1

1st Iteration Values -Assume h_2 = 0.190

h_2 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.1}$ ($m^3/s/m$)	$(q_w)_1$ ($m^3/s/m$)	h_2 (m) (Check)
0.190	0.296	0.664	1.151	0.313	0.687	0.191

2nd Iteration Values

h_2 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.1}$ ($m^3/s/m$)	$(q_w)_1$ ($m^3/s/m$)	h_2 (m) (Check)
0.191	0.296	0.664	1.151	0.313	0.687	0.191

Table 5.20 Second stage for the design application, second, third and fourth intervals

Interval: 2

1st Iteration Values -Assume h_3 = 0.105

h_3 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.2}$ (m^3/s/m)	$(q_w)_2$ (m^3/s/m)	h_3 (m) (Check)
0.105	0.148	0.726	1.259	0.242	0.445	0.107

2nd Iteration Values

h_3 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.2}$ (m^3/s/m)	$(q_w)_2$ (m^3/s/m)	h_3 (m) (Check)
0.107	0.149	0.726	1.258	0.243	0.444	0.106

Interval: 3

1st Iteration Values -Assume h_4 = 0.055

h_4 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.3}$ (m^3/s/m)	$(q_w)_3$ (m^3/s/m)	h_4 (m) (Check)
0.055	0.081	0.786	1.363	0.194	0.250	0.054

2nd Iteration Values

h_4 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.3}$ (m^3/s/m)	$(q_w)_3$ (m^3/s/m)	h_4 (m) (Check)
0.054	0.080	0.786	1.363	0.193	0.251	0.055

Interval: 4

1st Iteration Values -Assume h_5 = 0.020

h_5 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.4}$ (m^3/s/m)	$(q_w)_4$ (m^3/s/m)	h_5 (m) (Check)
0.020	0.037	0.869	1.507	0.145	0.105	0.021

2nd Iteration Values

h_5 (m)	h_{ave} (m)	μ_s	λ	$(q_w)_{i.4}$ (m^3/s/m)	$(q_w)_4$ (m^3/s/m)	h_5 (m) (Check)
0.021	0.038	0.867	1.503	0.146	0.104	0.021

Discharge values are shown below in Table 5.21. If the rack length is 2 m, 0.896 $m^3/s/m$ unit discharge is taken into the channel. This amount is higher than the required discharge value. However, bars can be clogged with tree branches and stones. If 10% of the trash rack is clogged, the desired discharge would still be taken into the intake channel. Furthermore, for the protection of the environment 10% of the flow is passing to the downstream of the structure which is an acceptable amount.

Table 5.21 Second stage for the design application, discharge values

Water diverted to the collection channel is:		
$(q_w)_{i.1}$ =	0.313	$m^3/s/m$
$(q_w)_{i.2}$ =	0.243	$m^3/s/m$
$(q_w)_{i.3}$ =	0.193	$m^3/s/m$
$(q_w)_{i.4}$ =	0.146	$m^3/s/m$
$(q_w)_i$ =	**0.896**	**$m^3/s/m$**
Discharge that passes over the trash rack and moves towards downstream is:		
$(q_w)_{out}$ =	**0.104**	**$m^3/s/m$**
Flow depth at the end of the trash rack is:		
h_5 =	**0.021**	**m**

5.3.1.2 Closed Form Solution Method

In the closed form solution method, a similar procedure like the previous method is applied. In the first stage of the design, stream discharge is assumed to be equal to the desired discharge amount. In Table 5.22 calculation results are shown. Flow depth at the end of the trash rack is assumed to be 0, which means all the flow is diverted to the intake channel. The required rack length is calculated by using the Frank’s method described in Equation (3.12) and a rack length of 3.087 m is obtained. To divert all the discharge a shorter rack length is chosen and L is decided to be 3 m.

Table 5.22 First stage for the design application

H_0 (m)	h_{cr} (m)	χ	h_1 (m)	
0.604	0.403	0.861	0.346	
L (m)	μ_s	λ	L	
3.000	0.650	1.127	3.087	> L
h_2 (m)	s			
0.000	0.087			
$(q_w)_i$ =	**0.799**	**m^3/s/m**		
$(q_w)_{out}$ =	**0.001**	**m^3/s/m**		

By assuming the design discharge is equal to the stream discharge, 3 m rack length is obtained. In the second stage, the real stream discharge is used in the calculation and the flow amount taken into the intake channel and the flow depth value at the end of the rack is obtained as shown in Table 5.23.

Table 5.23 Second stage for the design application.

h_{cr} (m)	χ	h_1 (m)	H_0 (m)	
0.467	0.861	0.402	0.700	
L (m)	μ_s	λ	L	
3.000	0.638	1.106	3.652	> L
h_2 (m)	s			
0.006	0.652			
$(q_w)_i$ =	**0.971**	**m^3/s/m**		
$(q_w)_{out}$ =	**0.029**	**m^3/s/m**		

Discharge taken into the weir is 0.971 m^3/s/m which is a higher value than expected. The structure seems to be on the safe side in terms of clogging but the downstream discharge is not enough for the sake of environmental aspects.

5.3.2 The Second Assumption: Constant Energy Head

5.3.2.1 Iterative Solution Method

In this method, a similar procedure described in analysis application is applied for the design of Tyrolean weir. Like the previous methods, again the design discharge is assumed to be the stream discharge for the first stage of the design. Flow depth calculation results are shown in Table 5.24.

Table 5.24 First stage for the design application, flow depth values.

Calculation of h_2

H_0 (m)	Δx (m)	ψ	h_{ave} (m)	μ_s	$\varphi (h_1/H_0)$	$\varphi (h_2/H_0)$	h_2 (m)
0.604	0.500	0.400	0.257	0.676	-0.386	-0.162	0.167

Calculation of h_3

h_{ave} (m)	μ_s	$\varphi (h_3/H_0)$	h_3 (m)
0.124	0.743	0.084	0.082

Calculation of h_4

h_{ave} (m)	μ_s	$\varphi (h_4/H_0)$	h_4 (m)
0.055	0.826	0.358	0.029

Calculation of h_5

h_{ave} (m)	μ_s	$\varphi (h_5/H_0)$	h_5 (m)
0.015	0.977	0.681	0.002

According to the flow depths obtained in Table 5.24, discharge amounts are calculated. At the end of fourth interval, h_5 flow depth is almost zero which means all the discharge is taken into the channel. So, four intervals with 0.5 m length, makes rack length equal to 2 m. In the second stage, stream discharge is taken as 1.00 $m^3/s/m$ and diverted flow is calculated (See Table 5.25).

Table 5.25 Second stage for the design application, discharge values.

Calculation of q_2

q_{max} ($m^3/s/m$)	h_{cr} (m)	
1.000	0.467	> h1 , Supercritical

ϕ (degree)	ϕ (radians)	β_1	β_2	ϕ (degree)	ϕ (radians)	$(q_w)_2$ ($m^3/s/m$)
300.000	5.236	-0.399	-0.217	268.958	4.694	0.688

Calculation of q_3

q_{max} ($m^3/s/m$)	h_{cr} (m)	
1.000	0.364	> h2 , Supercritical

ϕ (degree)	ϕ (radians)	β_2	β_3	ϕ (degree)	ϕ (radians)	$(q_w)_3$ ($m^3/s/m$)
268.958	4.694	-0.216	-0.034	257.842	4.500	0.450

Calculation of q_4

q_{max} ($m^3/s/m$)	h_{cr} (m)	
1.000	0.274	> h3 , Supercritical

ϕ (degree)	ϕ (radians)	β_3	β_4	ϕ (degree)	ϕ (radians)	$(q_w)_4$ ($m^3/s/m$)
257.842	4.500	-0.034	0.148	250.365	4.370	0.268

Calculation of q_5

q_{max} ($m^3/s/m$)	h_{cr} (m)	
1.000	0.194	> *h4* , Supercritical

ϕ (degree)	ϕ (radians)	β_4	β_5	ϕ (degree)	ϕ (radians)	$(q_w)_5$ ($m^3/s/m$)
250.365	4.370	0.149	0.331	245.184	4.279	0.135

$(q_w)_i$ = 0.865 $m^3/s/m$

$(q_w)_{out}$ = 0.135 $m^3/s/m$

Discharge values are shown above in Table 5.25. If the rack length is 2 m, 0.865 $m^3/s/m$ unit discharge is taken into the channel. This amount is higher than the required discharge value. However, bars can be clogged with tree branches and stones. If approximately 7% of the trash rack is clogged, the desired discharge would still be taken into the intake channel. Furthermore, for the protection of the environment 10% of the flow is passing to the downstream of the structure which is an acceptable amount.

5.3.2.2 Closed Form Solution Method:

This method is also applied in two stages. For the first stage again stream discharge is assumed the same as the desired discharge of the intake. First required rack length is studied as shown in the Table 5.26.

Table 5.26 First stage for the design application

h_{cr} (m)	h_1 (m)	H_0 (m)	
0.403	0.346	0.604	
S_L	D (mm)	C_d	L (m)
0.300	60.000	0.417	1.354
$(q_w)_{out}$ ($m^3/s/m$)	h_2 (m)		
0.000	0.000		
$(q_w)_i$ =	**0.800**	$m^3/s/m$	
$(q_w)_{out}$ =	**0.000**	$m^3/s/m$	

The required length of the rack is calculated for the 0.80 $m^3/s/m$ intake amount. For 1.354 m long rack, discharge passing to the downstream of the weir and h_2 the flow depth is at the end of the rack is both equal to 0. For the calculation of the discharge coefficient C_d, a different formula than the analysis application is used since in design example bar cross section is selected as circular. For the circular type, Equation (3.25) is used for obtaining C_d. The second stage calculations are shown in the Table 5.27.

Table 5.27 Second stage for the design application

h_{cr} (m)	***h_1*** (m)	***H_0*** (m)
0.467	0.402	0.700

S_L	***D*** (mm)	***C_d***	***L*** (m)
0.300	60.000	0.417	1.400

x		***h_2*** (m)	***$(q_w)_{out}$*** (m^3/s/m)
1.572	> *L* , Some part of the flow passes over the rack	0.029	0.106

$(q_w)_i$ = **0.894** **m^3/s/m**

$(q_w)_{out}$ = **0.106** **m^3/s/m**

In the second stage, stream discharge is 1.00 m^3/s/m and rack length value obtained in the first stage 1.354 m is rounded to 1.4 m for the ease of application. *x* value is the rack length required for diverting 1.00 m^3/s/m stream discharge and since it is higher than the decided rack length of 1.4 m, it is obvious that some part of the flow passes over the rack. According to the Equation (3.39), the flow depth at the end of trash rack is calculated and flow passing to the downstream is obtained by using Equation (3.40).

Discharge values are shown above in Table 5.27. If the rack length is 1.4 m, 0.894 m^3/s/m unit discharge is taken into the channel. This amount is higher than the required discharge value. However, bars can be clogged with tree branches and stones. If approximately 10% of the trash rack is clogged, the desired discharge would still be taken into the intake channel. Moreover, for the protection of the environment 10% of the flow is passing to the downstream of the structure, which is a reasonable amount.

In Table 5.28, one digit rack length values are listed according to the direct calculation methods. Lengths vary between 1.1 m and 3.8 m which is a high range for a reliable design.

Table 5.28 Comparison of rack length values obtained by direct calculations given by researchers

Method by Researcher	**Rack Length**
Frank	3.1 m
Noseda	2.3 m
Mostkow (Calculated C_d)	1.8 m
Mostkow (Constant C_d)	1.2 m
Brunella et al. (Calculated C_d)	3.7 m
Brunella et al. (Constant C_d)	1.1 m

Discharge values obtained by four different solution methods are listed below in Table 5.29 with rack lengths calculated by those methods.

Table 5.29 Comparison of results obtained from four different solution methods

	$(q_w)_i$ (m^3/s/m)	$(q_w)_{out}$ (m^3/s/m)	h (m)	L (m)
Constant Energy Level				
Iterative Solution Method	0.896	0.104	0.021	2.000
Closed Form Solution Method	0.971	0.029	0.006	3.000
Constant Energy Head				
Iterative Solution Method	0.865	0.135	0.017	2.000
Closed Form Solution Method	0.894	0.106	0.029	1.400

Closed form methods are developed for easier hand calculations so iterative methods give more precise results.

In this chapter two applications are presented. In these applications, analysis and design procedures are explained in terms of four different methods developed in past studies.

The first two methods assume constant energy level i.e. no headloss is considered throughout the rack length. In fact, the length of racks is relatively small for practical applications. Therefore, ignoring headloss may be assumed to yield insignificant error in computations. The consecutive methods assume constant energy head. So, this approach considers headloss but the energy grade line is assumed to be parallel to the rack surface. This assumption normally holds true for uniform flow. However, the flow rate along the rack decreases in flow direction which is accompanied by a decreasing non-uniform water surface profile along the flow direction. Hence, neither assumption is thoroughly correct. Therefore, the validity of the proposed approaches needs verification with reference to elaborated physical model studies.

CHAPTER 6

CONCLUSIONS AND FURTHER RECOMMENDATIONS

Tyrolean weirs are one of the most suitable structures for runoff river plants. If they are designed properly structure can work efficiently without high investment and environmental impact. Use of the program enables a designer to perform quick successive runs such that hydraulic conformity and cost aspects are easily assessed.

In the present study, design and analysis solution methods for Tyrolean intakes are researched and presented. A computer program named "Tyrol" is developed and application studies are demonstrated with step by step calculations for each method. Tyrol is easily applicable and user friendly.

In the analysis of the structure, usage of iterative methods for both constant energy level and constant energy head assumptions give similar results when compared to closed form solution methods. Closed form methods can misguide the designer if the structure is analyzed by using only closed form methods. In order to guide through the complex calculation procedure, a step by step solution is given for the analysis application.

In the design of the structure, most efficient values and ratios of parameters are presented according to the research made in past studies. With respect to these assumptions, most efficient design of a Tyrolean weir structure is given in detail and explained with a design application in Chapter 5. Formulae developed for the calculation of trash rack length give different results. So, calculated rack length results are compared with the results obtained from solution methods to give a better understanding. Selection of an appropriate value for L is recommended to be case sensitive considering local site characteristics. Therefore, final decision on L value is to be given by the designer.

Furthermore, the computer program Tyrol is developed for this study for an easy and user friendly way of analysis and design of Tyrolean weirs.

Recommendations for further studies can be as follows:

- Models can be built for different slopes, bar types and gaps since these are the governing properties of results.
- These models can be experimentally tested and results can be compared by the fast calculations made by using the computer program developed and presented in this study.
- So, different solution methods and assumptions can be compared and results can be checked in terms of their accuracy according to the real situations and values observed and obtained from physical models.

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APPENDIX

SOURCE CODE FOR THE SOFTWARE

```
Imports System

Imports System.Drawing

Imports System.Windows.Forms

Public Class Form1

    Inherits System.Windows.Forms.Form

    Private buttonPanel As New Panel

    Private WithEvents OutputTable As New DataGridView

    Private textDialog As SaveFileDialog

    'Declare variables  q0, h0, channelWidth, L, Ɛ, Δx, Ho, n, m, hAvg, ψ, λ, μs, Lq, s2, a, b, c, root1, root2, disc (for solving parabolic eqns), ΦCheck, qCheck, qinTotal, qRelease, qmax, hcr, βCheck, hRelease, Cd as double-precision variables

    Dim q0, h0, channelWidth, L, Ɛ, Δx, Ho, n, m, hAvg, ψ, λ, μs, Lq, s2, a, b, c, root1, root2, disc, ΦCheck, qCheck, qinTotal, qRelease, qmax, hcr, βCheck, hRelease, Cd, sL, t, D, V0 As Double

    Dim i As Integer
```

```
Dim q(1000), h(1000), qIn(1000), Φ(1000), β(1000), ϕ(1000) As Double

Const g As Double = 9.81

Const degToRad As Double = 0.0174532925199433

Private Sub Button1_Click(sender As Object, e As EventArgs) Handles Button1.Click

    If (String.IsNullOrEmpty(h1Height.Text)) Then

        MessageBox.Show("Please Enter a Water Height Value")

        Return

    End If

    If (String.IsNullOrEmpty(barDistFromEdge.Text)) Then

        MessageBox.Show("Please Enter n Value")

        Return

    End If

    If (String.IsNullOrEmpty(barDistFromCenter.Text)) Then

        MessageBox.Show("Please Enter m Value")

        Return

    End If

    If (String.IsNullOrEmpty(angleOfBars.Text)) Then

        MessageBox.Show("Please Enter a Trash Rack Slope Angle")
```

```
        Return
    End If
    If (String.IsNullOrEmpty(rackLength.Text)) Then
        MessageBox.Show("Please enter a Bar Length (L) Value")
        Return
    End If
    If (String.IsNullOrEmpty(Discharge0.Text)) Then
        MessageBox.Show("Please Enter a Discharge Value")
        Return
    End If
    If (String.IsNullOrEmpty(Wdth.Text)) Then
        MessageBox.Show("Please Enter a Channel Width (B) Value ")
        Return
    End If
    If ComboBox1.Text = "Rectangular Reinforced Circular Bars (Recomended)"
Then
        If (String.IsNullOrEmpty(rndBarDia.Text)) Then
            MessageBox.Show("Please Enter a Bar Diameter Value ")
            Return
```

```
    End If
End If
If ComboBox1.Text = "Ovoid Bars" Then
    If (String.IsNullOrEmpty(rndBarDia.Text)) Then
        MessageBox.Show("Please Enter a Bar Diameter Value ")
        Return
    End If
End If
If ComboBox1.Text = "Circular Bars" Then
    If (String.IsNullOrEmpty(rndBarDia.Text)) Then
        MessageBox.Show("Please Enter a Bar Diameter Value ")
        Return
    End If
End If
'Constant Energy Level  - Iterative Method Condition
If ConsELIterativeRadioBtn.Checked Then Solution1()
'Constant Energy Level  - Closed Form Method Condition
If ConsELClosedRadioBtn.Checked Then Solution2()
```

```
'Constant Energy Head  - Iterative Method Condition

If ConsEHIterativeRadioBtn.Checked Then Solution3()

'Constant Energy Head  - Closed Form Method Condition - Flat Bars

If ConsEHClosedRadioBtn.Checked Then If ComboBox1.Text = "Rectangular Bars" Then Solution4()

If ConsEHClosedRadioBtn.Checked Then If ComboBox1.Text = "Rounded-Headed Bars" Then Solution4()

If ConsEHClosedRadioBtn.Checked Then If ComboBox1.Text = "T-Shaped Bars" Then Solution4()

'Constant Energy Head  - Closed Form Method Condition - Round Bars

If ConsEHClosedRadioBtn.Checked Then If ComboBox1.Text = "Rectangular Reinforced Circular Bars (Recomended)" Then Solution5()

If ConsEHClosedRadioBtn.Checked Then If ComboBox1.Text = "Circular Bars" Then Solution5()

If ConsEHClosedRadioBtn.Checked Then If ComboBox1.Text = "Ovoid Bars" Then Solution5()

Button1.Enabled = False

End Sub

Private Sub Solution1() 'Constant Energy Level  - Iterative Method

channelWidth = Wdth.Text

q0 = Discharge0.Text / channelWidth
```

```
h(1) = h1Height.Text

m = barDistFromCenter.Text

n = barDistFromEdge.Text

L = rackLength.Text

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 2" Then Δx = L / 2

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 4" Then Δx = L / 4

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 5" Then Δx = L / 5

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 10" Then Δx = L / 10

If deltaxCheckBox.CheckState = CheckState.Unchecked Then Δx = L / 100

Ɛ = angleOfBars.Text

ψ = n / m

i = 1

q(1) = q0


Ho = (q(1) / h(1)) ^ 2 / (2 * g) + h(1) * System.Math.Cos(Ɛ * degToRad)

Do Until i = L / Δx + 1
```

```
        h(i + 1) = h(i)

        Do

            h(i + 1) = h(i + 1) - 0.000001

            hAvg = (h(i) + h(i + 1)) / 2

            If NosedasContractionCoeffRadioBtn.Checked Then μs = 0.66 * ψ ^ (-0.16) * (m / 1000 / hAvg) ^ 0.13

            If ConstantContractionCoeffRadioBtn.Checked Then μs = ConstantContractionCoeffValue.Text

            λ = ψ * μs * (2 * g * System.Math.Cos(Ɛ * degToRad)) ^ 0.5

            qIn(i) = λ * hAvg ^ 0.5 * Δx

            q(i + 1) = q(i) - qIn(i)

            qCheck = h(i + 1) * (2 * g * ((Ho + Δx * i * System.Math.Sin(Ɛ * degToRad)) - h(i + 1) * System.Math.Cos(Ɛ * degToRad))) ^ 0.5

        Loop While qCheck - q(i + 1) > 0.0001 And qCheck > 0 And q(i + 1) > 0

        i += 1

    Loop

    If q(i + 1) < 0 Then q(i) = 0 And qIn(i) = 0 And h(i) = 0 And qIn(i + 1) = 0 And h(i + 1) = 0 And q(i + 1) = 0

    For Each item In qIn

        qinTotal = qinTotal + item
```

```
        Next
        If qinTotal > q0 Then qinTotal = q0
        qRelease = q0 - qinTotal
        h(1) = System.Math.Round(h(1), 3)
        h(i) = System.Math.Round(h(i), 3)
        qinTotal = System.Math.Round(qinTotal, 3)
        qRelease = System.Math.Round(qRelease, 3)
        SetupDataGridView()
        PopulateDataGridView()
        OutputTable.Rows(0).HeaderCell.Value = "Constant Energy Level  - Iterative
Solution"
    End Sub
    Private Sub Solution2() 'Constant Energy Level - Closed Form Method
        'Assign textbox values to variables
        channelWidth = Wdth.Text
        q0 = Discharge0.Text / channelWidth
        h(1) = h1Height.Text
        m = barDistFromCenter.Text
        n = barDistFromEdge.Text
```

```
L = rackLength.Text

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 2" Then Δx = L / 2

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 4" Then Δx = L / 4

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 5" Then Δx = L / 5

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 10" Then Δx = L / 10

If deltaxCheckBox.CheckState = CheckState.Unchecked Then Δx = L / 100

Ɛ = angleOfBars.Text

ψ = n / m

q(1) = q0

If NosedasContractionCoeffRadioBtn.Checked Then µs = 0.66 * ψ ^ (-0.16) * (m / 1000 / h(1)) ^ 0.13

If ConstantContractionCoeffRadioBtn.Checked Then µs = ConstantContractionCoeffValue.Text

λ = ψ * µs * (2 * g * System.Math.Cos(Ɛ * degToRad)) ^ 0.5

Lq = 2.561 * q0 / λ / (h(1) ^ 0.5)

If Lq > L Then

    s2 = Lq - L
```

```
    ' h2^2 - 2*h2*h1 + s2^2 / Lq^2 = 0
Else
    s2 = Lq
End If
a = 1
b = -2 * h(1)
c = h(1) ^ 2 * s2 ^ 2 / Lq ^ 2
disc = b ^ 2 - 4 * a * c
If disc >= 0 Then
    root1 = (-b + disc ^ 0.5) / (2 * a)
    root2 = (-b - disc ^ 0.5) / (2 * a)
Else
    MessageBox.Show("No Real Root for h!")
End If
If System.Math.Abs(root1) < h(1) Then
    hRelease = root1
Else
    hRelease = root2
```

```
        End If
        qinTotal = 1.707 * q0 * (2 - (1 + hRelease / h(1)) * ((2 - hRelease / h(1)) ^ 0.5))
        qRelease = q0 - qinTotal
        h(1) = System.Math.Round(h(1), 2)
        h(i) = System.Math.Round(hRelease, 2)
        qinTotal = System.Math.Round(qinTotal, 2)
        qRelease = System.Math.Round(qRelease, 2)
        SetupDataGridView()
        PopulateDataGridView()
        OutputTable.Rows(0).HeaderCell.Value = "Constant Energy Level - Closed Form Solution"
    End Sub
    Private Sub Solution3() 'Constant Energy Head - Iterative Method
        'Assign textbox values to variables
        channelWidth = Wdth.Text
        q0 = Discharge0.Text / channelWidth
        h(1) = h1Height.Text
        m = barDistFromCenter.Text
        n = barDistFromEdge.Text
```

```
L = rackLength.Text

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 2" Then Δx = L / 2

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 4" Then Δx = L / 4

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 5" Then Δx = L / 5

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 10" Then Δx = L / 10

If deltaxCheckBox.CheckState = CheckState.Unchecked Then Δx = L / 100

Ɛ = angleOfBars.Text

ψ = n / m

i = 1

q(1) = q0

Ho = (q(1) / h(1)) ^ 2 / (2 * g) + h(1) * System.Math.Cos(Ɛ * degToRad)

Do Until i = L / Δx + 1

  h(i + 1) = h(i)

  Do

    h(i + 1) = h(i + 1) - 0.000001

    hAvg = (h(i) + h(i + 1)) / 2
```

```
            If NosedasContractionCoeffRadioBtn.Checked Then μs = 0.66 * ψ ^ (-0.16) * (m / 1000 / hAvg) ^ 0.13

            If ConstantContractionCoeffRadioBtn.Checked Then μs = ConstantContractionCoeffValue.Text

            Φ(i) = (System.Math.Acos((h(i) / Ho) ^ 0.5)) / 2 - 3 / 2 * (h(i) / Ho * (1 - h(i) / Ho)) ^ 0.5

            Φ(i + 1) = (System.Math.Acos((h(i + 1) / Ho) ^ 0.5)) / 2 - 3 / 2 * (h(i + 1) / Ho * (1 - h(i + 1) / Ho)) ^ 0.5

            ΦCheck = Δx * μs * ψ / Ho + Φ(i)

        Loop While ΦCheck > Φ(i + 1)

        i += 1

    Loop

    i = 1

    Do Until i = L / Δx + 1

        q(i + 1) = q(i)

        Do

            q(i + 1) = q(i + 1) - 0.000001

            hAvg = (h(i) + h(i + 1)) / 2

            μs = 0.66 * ψ ^ (-0.16) * (m / 1000 / hAvg) ^ 0.13

            qmax = 2 * ((2 * g) ^ 0.5) / 3 / (3 ^ 0.5) * Ho ^ (3 / 2)
```

```
            hcr = (q(i) ^ 2 / g) ^ (1 / 3)

            If h(i) < hcr Then

               'Supercritical Flow

               ϕ(i) = 1 / 3 * System.Math.Acos(1 - 2 * (q(i) / qmax) ^ 2) / degToRad +
240

               ϕ(i + 1) = 1 / 3 * System.Math.Acos(1 - 2 * (q(i + 1) / qmax) ^ 2) /
degToRad + 240

            ElseIf h(i) > hcr Then

               'Subcritical Flow

               ϕ(i) = 1 / 3 * System.Math.Acos(1 - 2 * (q(i) / qmax) ^ 2) / degToRad

               ϕ(i + 1) = 1 / 3 * System.Math.Acos(1 - 2 * (q(i + 1) / qmax) ^ 2) /
degToRad

            End If

            β(i) = 1 / 2 * System.Math.Acos(1 / (3 ^ 0.5) * (2 * System.Math.Cos(ϕ(i)
* degToRad) + 1) ^ 0.5) - 2 ^ 0.5 / 2 * ((2 * System.Math.Cos(ϕ(i) * degToRad) + 1)
* (1 - System.Math.Cos(ϕ(i) * degToRad))) ^ 0.5

            β(i + 1) = 1 / 2 * System.Math.Acos(1 / (3 ^ 0.5) * (2 *
System.Math.Cos(ϕ(i + 1) * degToRad) + 1) ^ 0.5) - 2 ^ 0.5 / 2 * ((2 *
System.Math.Cos(ϕ(i + 1) * degToRad) + 1) * (1 - System.Math.Cos(ϕ(i + 1) *
degToRad))) ^ 0.5

            βCheck = Δx * μs * ψ / Ho + β(i)

         Loop While βCheck > β(i + 1)
```

```
        i += 1
      Loop
      qinTotal = q0 - q(i)
      qRelease = q(i)
      h(1) = System.Math.Round(h(1), 3)
      h(i) = System.Math.Round(h(i), 3)
      qinTotal = System.Math.Round(qinTotal, 3)
      qRelease = System.Math.Round(qRelease, 3)
      SetupDataGridView()
      PopulateDataGridView()
      OutputTable.Rows(0).HeaderCell.Value = "Constant Energy Head - Iterative
Solution"
    End Sub
    Private Sub Solution4() 'Constant Energy Head - Closed Form Method - Flat Bars
      channelWidth = Wdth.Text
      q0 = Discharge0.Text / channelWidth
      h(1) = h1Height.Text
      m = barDistFromCenter.Text
      n = barDistFromEdge.Text
```

```
L = rackLength.Text

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 2" Then Δx = L / 2

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 4" Then Δx = L / 4

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 5" Then Δx = L / 5

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 10" Then Δx = L / 10

If deltaxCheckBox.CheckState = CheckState.Unchecked Then Δx = L / 100

Ɛ = angleOfBars.Text

D = Double.Parse(rndBarDia.Text)

ψ = n / m

h0 = h(1)

Ho = (q(1) / h(1)) ^ 2 / (2 * g) + h(1) * System.Math.Cos(Ɛ * degToRad)

hRelease = h(1)

sL = System.Math.Tan(Ɛ * degToRad) 'Slope of rack bars

t = m - n

hcr = (q0 ^ 2 / g) ^ (1 / 3)

V0 = q0 / h0
```

```
Cd = 0.1296 * (t / n) - 0.4284 * sL ^ 2 + 0.1764
Lq = Ho / Cd / ψ * (h(1) / Ho * (1 - h(1) / Ho) ^ 0.5)
If (Lq < L) Then
    qinTotal = q0
    qRelease = 0
    hRelease = 0
ElseIf (Lq > L) Then
    Do Until System.Math.Round(Lq, 2) = System.Math.Round(L, 2)
        hRelease = hRelease - 0.001
        Lq = Ho / Cd / ψ * (h(1) / Ho * (1 - h(1) / Ho) ^ 0.5 - hRelease / Ho * (1 - hRelease / Ho) ^ 0.5)
    Loop
    qRelease = hRelease * (2 * g * (Ho - hRelease)) ^ 0.5
End If
qinTotal = q0 - qRelease
h(1) = System.Math.Round(h(1), 3)
h(i) = System.Math.Round(hRelease, 3)
qinTotal = System.Math.Round(qinTotal, 3)
qRelease = System.Math.Round(qRelease, 3)
```

```
SetupDataGridView()

PopulateDataGridView()

OutputTable.Rows(0).HeaderCell.Value = "Constant Energy Head - Closed Form Solution (Flat Bars)"

End Sub

Private Sub Solution5() 'Constant Energy Head - Closed Form Method - Round Bars

channelWidth = Wdth.Text

q0 = Discharge0.Text / channelWidth

h(1) = h1Height.Text

m = barDistFromCenter.Text

n = barDistFromEdge.Text

L = rackLength.Text


If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 2" Then Δx = L / 2

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 4" Then Δx = L / 4

If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 5" Then Δx = L / 5
```

```
If deltaxCheckBox.CheckState = CheckState.Checked Then If deltaxComboBox.Text = "L / 10" Then Δx = L / 10

If deltaxCheckBox.CheckState = CheckState.Unchecked Then Δx = L / 100

Ɛ = angleOfBars.Text

D = Double.Parse(rndBarDia.Text)

ψ = n / m

Ho = (q(1) / h(1)) ^ 2 / (2 * g) + h(1) * System.Math.Cos(Ɛ * degToRad)

hRelease = h(1)

sL = System.Math.Tan(Ɛ * degToRad) 'Slope of rack bars

t = m - n

hcr = (q0 ^ 2 / g) ^ (1 / 3)

V0 = q0 / h0

If h0 > hcr Then

    Cd = 0.53 + 0.4 * System.Math.Log10(D / n) - 0.61 * sL

Else : Cd = 0.39 + 0.27 * System.Math.Log10(D / n) - 0.8 * V0 ^ 2 / (2 * g * Ho) - 0.5 * System.Math.Log10(sL)

End If

Lq = Ho / Cd / ψ * (h(1) / Ho * (1 - h(1) / Ho) ^ 0.5)

If (Lq < L) Then
```

```
            qinTotal = q0
            qRelease = 0
            hRelease = 0
        ElseIf (Lq > L) Then
            Do Until System.Math.Round(Lq, 2) = System.Math.Round(L, 2)
                hRelease = hRelease - 0.001
                Lq = Ho / Cd / ψ * (h(1) / Ho * (1 - h(1) / Ho) ^ 0.5 - hRelease / Ho * (1 -
hRelease / Ho) ^ 0.5)
            Loop
            qRelease = hRelease * (2 * g * (Ho - hRelease)) ^ 0.5
        End If
        qinTotal = q0 - qRelease
        h(1) = System.Math.Round(h(1), 3)
        h(i) = System.Math.Round(hRelease, 3)
        qinTotal = System.Math.Round(qinTotal, 3)
        qRelease = System.Math.Round(qRelease, 3)
        SetupDataGridView()
        PopulateDataGridView()
```

```
        OutputTable.Rows(0).HeaderCell.Value = "Constant Energy Head - Closed
Form Solution (Round Bars)"

    End Sub

    Private Sub SetupDataGridView()

        Me.Controls.Add(OutputTable)

        OutputTable.ColumnCount = 4

        With OutputTable.ColumnHeadersDefaultCellStyle

            .BackColor = Color.Navy

            .ForeColor = Color.White

            .Font = New Font(OutputTable.Font, FontStyle.Bold)

        End With

        With OutputTable

            .Name = "Results"

            .Location = New Point(595, 358)

            .Size = New Size(668, 75)

            .AutoSizeColumnsMode = DataGridViewAutoSizeColumnsMode.AllCells

            .AutoSizeRowsMode = DataGridViewAutoSizeRowsMode.AllCells

            .ColumnHeadersBorderStyle = DataGridViewHeaderBorderStyle.Single

            .CellBorderStyle = DataGridViewCellBorderStyle.Single
```

```
            .GridColor = Color.Black

            .RowHeadersVisible = True

            .RowHeadersWidthSizeMode =
DataGridViewRowHeadersWidthSizeMode.AutoSizeToAllHeaders

            .Columns(0).Name = "h1 (m)"

            .Columns(1).Name = "h Release (m)"

            .Columns(2).Name = "q Channel (m3/s/m)"

            .Columns(3).Name = "q Release (m3/s/m)"

            .SelectionMode = DataGridViewSelectionMode.FullRowSelect

            .MultiSelect = True

            .ReadOnly = True

            .BringToFront()

            .Dock = DockStyle.None

        End With

    End Sub

    Private Sub PopulateDataGridView()

        Dim row0 As String() = {h(1), h(i), qinTotal, qRelease}

        With Me.OutputTable.Rows

            .Add(row0)
```

```
        End With
        With Me.OutputTable
            .Columns(0).DisplayIndex = 0
            .Columns(1).DisplayIndex = 1
            .Columns(2).DisplayIndex = 2
            .Columns(3).DisplayIndex = 3
             End With
    End Sub
    Private Sub NewToolStripButton_Click(sender As Object, e As EventArgs)
Handles NewToolStripButton.Click
        If MsgBox("Do you want to save before quit?", MsgBoxStyle.YesNo, "Program
will close!") = MsgBoxResult.Yes Then
            SaveFileDialog1.Filter = "Text Document|*.txt; *.txt"
            If SaveFileDialog1.ShowDialog = Windows.Forms.DialogResult.OK _
            Then
                My.Computer.FileSystem.WriteAllText _
                (SaveFileDialog1.FileName, RichTextBox1.Text, True)
            End If
        Else
```

```
            Application.Restart()
        End If
    End Sub
    Private Sub NewToolStripMenuItem_Click(sender As Object, e As EventArgs)
Handles NewToolStripMenuItem.Click
        If MsgBox("Do you want to save before quit?", MsgBoxStyle.YesNo, "Program
will close!") = MsgBoxResult.Yes Then
            SaveFileDialog1.Filter = "Text Document|*.txt; *.txt"
            If SaveFileDialog1.ShowDialog = Windows.Forms.DialogResult.OK _
            Then
                My.Computer.FileSystem.WriteAllText _
                (SaveFileDialog1.FileName, RichTextBox1.Text, True)
            End If
        Else
            Application.Restart()
        End If
    End Sub
    Private Sub ExitToolStripMenuItem_Click(sender As Object, e As EventArgs)
Handles ExitToolStripMenuItem.Click
        Close()
```

```
    End Sub



    Private Sub SaveToolStripMenuItem_Click(sender As Object, e As EventArgs) Handles SaveToolStripMenuItem.Click

        SaveFileDialog1.Filter = "Text Document|*.txt; *.txt"

        If SaveFileDialog1.ShowDialog = Windows.Forms.DialogResult.OK _

        Then

            My.Computer.FileSystem.WriteAllText _

            (SaveFileDialog1.FileName, RichTextBox1.Text, True)

        End If

    End Sub

    Private Sub SaveToolStripButton_Click(sender As Object, e As EventArgs) Handles SaveToolStripButton.Click

        SaveFileDialog1.Filter = "Text Document|*.txt; *.txt"

        If SaveFileDialog1.ShowDialog = Windows.Forms.DialogResult.OK _

        Then

            My.Computer.FileSystem.WriteAllText _

            (SaveFileDialog1.FileName, RichTextBox1.Text, True)

        End If
```

```
End Sub

Private Sub ComboBox1_SelectedIndexChanged(sender As Object, e As EventArgs) Handles ComboBox1.SelectedIndexChanged

    If ComboBox1.Text = "Rectangular Reinforced Circular Bars (Recomended)" Then ConstantContractionCoeffValue.Text = 0.85

    If ComboBox1.Text = "Rectangular Reinforced Circular Bars (Recomended)" Then barTypePicBox.Image = My.Resources.circularWithRectangular

    If ComboBox1.Text = "Rectangular Reinforced Circular Bars (Recomended)" Then rndBarDia.Enabled = True

    If ComboBox1.Text = "Rectangular Reinforced Circular Bars (Recomended)" Then rndBarDiaLabel.Enabled = True

    If ComboBox1.Text = "Rectangular Reinforced Circular Bars (Recomended)" Then rndBarUnitLabel.Enabled = True

    If ComboBox1.Text = "Circular Bars" Then barTypePicBox.Image = My.Resources.circular

    If ComboBox1.Text = "Circular Bars" Then ConstantContractionCoeffValue.Text = 0.85

    If ComboBox1.Text = "Circular Bars" Then rndBarDia.Enabled = True

    If ComboBox1.Text = "Circular Bars" Then rndBarDiaLabel.Enabled = True

    If ComboBox1.Text = "Circular Bars" Then rndBarUnitLabel.Enabled = True

    If ComboBox1.Text = "Ovoid Bars" Then ConstantContractionCoeffValue.Text = 0.9
```

If ComboBox1.Text = "Ovoid Bars" Then barTypePicBox.Image = My.Resources.Ovoid

If ComboBox1.Text = "Ovoid Bars" Then rndBarDia.Enabled = True

If ComboBox1.Text = "Ovoid Bars" Then rndBarDiaLabel.Enabled = True

If ComboBox1.Text = "Ovoid Bars" Then rndBarUnitLabel.Enabled = True

If ComboBox1.Text = "Rectangular Bars" Then ConstantContractionCoeffValue.Text = 0.63

If ComboBox1.Text = "Rectangular Bars" Then barTypePicBox.Image = My.Resources.Rectangular

If ComboBox1.Text = "Rectangular Bars" Then rndBarDia.Enabled = False

If ComboBox1.Text = "Rectangular Bars" Then rndBarDiaLabel.Enabled = False

If ComboBox1.Text = "Rectangular Bars" Then rndBarUnitLabel.Enabled = False

If ComboBox1.Text = "Rounded-Headed Bars" Then ConstantContractionCoeffValue.Text = 0.8

If ComboBox1.Text = "Rounded-Headed Bars" Then barTypePicBox.Image = My.Resources.roundedHeaded

If ComboBox1.Text = "Rounded-Headed Bars" Then rndBarDia.Enabled = False

If ComboBox1.Text = "Rounded-Headed Bars" Then rndBarDiaLabel.Enabled = False

```
If ComboBox1.Text = "Rounded-Headed Bars" Then rndBarUnitLabel.Enabled = False

If ComboBox1.Text = "T-Shaped Bars" Then ConstantContractionCoeffValue.Text = 0.63

If ComboBox1.Text = "T-Shaped Bars" Then barTypePicBox.Image = My.Resources.tShaped

If ComboBox1.Text = "T-Shaped Bars" Then rndBarDia.Enabled = False

If ComboBox1.Text = "T-Shaped Bars" Then rndBarDiaLabel.Enabled = False

If ComboBox1.Text = "T-Shaped Bars" Then rndBarUnitLabel.Enabled = False

End Sub

Private Sub ConsELIterativeRadioBtn_CheckedChanged(sender As Object, e As EventArgs) Handles ConsELIterativeRadioBtn.CheckedChanged

If ConsELIterativeRadioBtn.Checked Then PictureBox1.Image = My.Resources.constantEnergyLevel1

End Sub

Private Sub ConsELClosedRadioBtn_CheckedChanged(sender As Object, e As EventArgs) Handles ConsELClosedRadioBtn.CheckedChanged

If ConsELClosedRadioBtn.Checked Then PictureBox1.Image = My.Resources.constantEnergyLevel1

End Sub

Private Sub ConsEHIterativeRadioBtn_CheckedChanged(sender As Object, e As EventArgs) Handles ConsEHIterativeRadioBtn.CheckedChanged
```

```
        If ConsEHIterativeRadioBtn.Checked Then PictureBox1.Image = My.Resources.constantEnergyHead1

    End Sub

    Private Sub ConsEHClosedRadioBtn_CheckedChanged(sender As Object, e As EventArgs) Handles ConsEHClosedRadioBtn.CheckedChanged

        If ConsEHClosedRadioBtn.Checked Then PictureBox1.Image = My.Resources.constantEnergyHead1

    End Sub

    Private Sub valueΔx_CheckedChanged(sender As Object, e As EventArgs) Handles deltaxCheckBox.CheckedChanged

        If deltaxCheckBox.Checked Then deltaxComboBox.Enabled = True

        If deltaxCheckBox.Checked Then deltaxLabel.Enabled = True

        If deltaxCheckBox.Checked Then deltaxUnitLabel.Enabled = True

        If deltaxCheckBox.CheckState = CheckState.Unchecked Then deltaxComboBox.Enabled = False

        If deltaxCheckBox.CheckState = CheckState.Unchecked Then deltaxLabel.Enabled = False

        If deltaxCheckBox.CheckState = CheckState.Unchecked Then deltaxUnitLabel.Enabled = False

    End Sub

End Class
```