

COMPUTER AIDED FLOW ANALYSIS THROUGH CULVERTS AND
DIVERSION TUNNELS

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DIVERSION TUNNELS**

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ABSTRACT

COMPUTER AIDED FLOW ANALYSIS THROUGH CULVERTS AND DIVERSION TUNNELS

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Culverts and diversion tunnels are structures that can be exposed to many different hydraulic conditions throughout their lifetime. It is essential to know the flow behaviors that will occur in these conduits to size them and take the necessary precautions. In order to understand the characteristics of these conditions, a number of analyses should be made. In this study, all possible hydraulic situations that may occur throughout these conduits are examined by considering the tunnel structure as a long-span culvert. A software has been developed to do such analyses using a user's set of data and show the results in the form of graphics and tables. As a consequence, the performance curve and the water surface profile according to various flow rates were obtained. In addition, the operability of the conduit as a storage structure is examined, and routing analyses are produced in this direction. To demonstrate how to use the software and describe the findings of the analyses, example cases are generated and discussions are presented.

Keywords: Culvert, Diversion Tunnel, Water Surface Profile, Gradually Varied Flow, Storage Routing

ÖZ

MENFEZ VE DERİVASYON TÜNELLERİNDE BİLGİSAYAR DESTEKLİ AKIM ANALİZİ

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Yüksek Lisans, İnşaat Mühendisliği
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Menfezler ve derivasyon tünelleri, kullanım ömürleri boyunca birçok farklı hidrolik akım durumuna maruz kalabilecek yapılardır. Bu kapalı iletim yapılarını boyutlandırmak ve gerekli önlemleri alabilmek açısından içlerinde oluşabilecek akım davranışlarının bilinmesi önemlidir. Bu durumların anlaşılabilmesi için bazı analizlerin gerçekleştirilmesi gerekir. Bu çalışmada, tünel yapısı geniş açıklıklı bir menfez olarak ele alınarak, yapı boyunca oluşabilecek tüm hidrolik durumlar incelenmiştir. Bu araştırma sonucunda, kullanıcının veri girişini sağlayacağı ve sonuçların grafik ve tablo olarak gösterileceği bir yazılım geliştirilmiştir. Böylece, çeşitli debilere ait performans eğrisi ve su yüzü profili elde edilmiştir. Buna ek olarak, iletim yapısının bir depolama yapısı olarak çalışabilme durumu incelenmiş ve öteleme analizleri yapılmıştır. Geliştirilen yazılımın kullanımının gösterilmesi ve analiz sonuçlarının açıklanması ve tartışılması için örnek durumlar üretilmiştir.

Anahtar Kelimeler: Menfez, Derivasyon Tüneli, Su Yüzü Profili, Yavaş Değişen Akım, Hazne Ötelemesi



To my family...

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LIST OF SYMBOLS

A	Cross-sectional area
a	Coefficient of area-elevation relationship
$A(H_r)$	Area-elevation relationship
b	Coefficient of area-elevation relationship
c	Coefficient of area-elevation relationship
c_K	Inlet loss coefficient
c_s	S_c Curve coefficient
D	Interior height of conduit
D_{eq}	Equivalent culvert diameter
D_H	Hydraulic depth
E	Specific energy
F	Specific force
F_r	Froude number
g	Gravitational acceleration
H_b	Bending loss
H_e	Entrance loss
H_f	Friction loss
H_j	Junction loss
H_L	Total energy loss
H_o	Outlet loss
H_r	Reservoir surface elevation
HW	Headwater
$I(t)$	Inflow hydrograph
I_{av}	Average of the two successive inflows
I_p	Peak inflow rate

K_b	Bending coefficient
K_e	Entrance coefficient
K_{exit}	Exit coefficient
K_s	Slope coefficient
L	Culvert or tunnel length
L_f	Full barrel length
L_{fr}	Free barrel length
L_j	Hydraulic jump length
M	Momentum
M_K	Inlet loss coefficient
n	Manning's roughness coefficient
P	Wetted perimeter
Q	Discharge
$Q(H_r)$	Outflow-elevation relationship
Q_{av}	Average of the two successive outflows
R	Hydraulic radius
R_c	Radius of curvature
S_c	Critical slope
S_f	Friction slope
S_o	Culvert or tunnel slope
T	Top width
t	Instantaneous time
t_p	Time to peak
TW	Tailwater depth
u	Average velocity
u_c	Critical velocity

u_d	Downstream velocity
u_o	Outlet velocity
u_u	Upstream velocity
V_{acc}	Difference between the volume of inflow and outflow
V_i	Volume obtained by area-elevation relation
V_{in}	Volume created by inflow
V_{out}	Volume created by outflow
V_r	Reservoir volume in addition to V_{acc}
y	Flow depth
Y	Inlet loss coefficient
y/D	Percent fullness ratio
y_c	Critical depth
y_n	Normal depth
y_o	Outlet depth
z	Distance in vertical axis
α	S_c Curve coefficient
α_e	Energy correction coefficient
β	S_c Curve coefficient
γ	S_c Curve coefficient
Δt	Time interval
Δx	Distance between two successive sections
Δy	Elevation difference between two successive sections
ε	S_c Curve coefficient
θ	Central angle of cross-sectional area of circular segment
$\bar{y}$	Distance from the water surface to the centroid of the cross-sectional area

CHAPTER 1

INTRODUCTION

1.1 General

The diversion of streamflow around or through a dam site during construction must be considered in the design of a dam that will be built over a waterway. The size and flood potential of the stream determines the magnitude of the diversion problem. At some dam sites, diversion may be costly and time-demanding, causing construction delayed activities whereas at other sites, diversion may not be a significant issue. Nonetheless, all sites, except that located offstream, have a diversion problem at some level, and choosing the best effective diversion strategy during construction is critical to the economy of the dam (USBR, 1987).

Although diversion is a significant step for dam design, there are few studies on diversion hydraulics in the literature. A tunnel that carries a watercourse is a very uncommon structure. However, the hydraulic performance of such a structure will be similar to that of a conventional culvert (Balkham et al., 2010).

Culvert is a conduit that conveys flow under a roadway, railroad, or any kind of other earthen embankments. Although culverts are simple hydraulic structures, their flow conditions can vary according to inlet configurations, shapes, slopes, barrel roughness, and outlet conditions.

In the studies carried out from the past to the present, culvert hydraulics has always been referred to as special studies. As a pioneering study, Yarnell, Nagler, and Woodward published a bulletin named “The Flow of Water Through Culverts”, and they reported their experiments on culverts. More than 3000 experiments were conducted for concrete pipe culverts and concrete box culverts (Yarnell et al., 1926).

Later Mavis (1942) examined round smooth pipe culverts. In addition, the U.S. Bureau of Reclamation has conducted a comprehensive experimental investigation on the hydraulic behavior of regularly used pipe culverts (French, 1955, as cited in Chow, 1959). Not only has the material supplied in this first work grown too limited in scope for modern requirements, but methods of experimentation, interpretation, and application of results have also evolved significantly in the intervening years. As a result, additional culvert studies have been performed in several laboratories, with funding provided primarily by state and federal agencies (Metzler and Rouse, 1959). Federal Highway Administration (FHWA) published a comprehensive report about all hydraulic conditions of culverts. The present study has been developed mainly by following the detailed guidelines recommended by FHWA.

Hotchkiss et al. (2008) compared several computer programs that analyzes culvert hydraulics, such as HY-8, FishXing, and CulvertMaster and found different limitations. As part of an effort to update the HY-8 program, the study of Hotchkiss et al. (2008) compares the available hydraulic features and tests the validity of these other programs. HY-8 is the software developed by FHWA in the scope of the report published. The software can analyze various section types under different inlet and outlet configurations for culverts. In this thesis, studies have been carried out concerning capabilities of HY-8. Table 1.1 compares the general features of several computer programs and the software, C-PAS, developed in this thesis. As can be seen from Table 1.1, C-PAS has been specifically developed to fill a gap in the literature of computer aided flow analysis through culverts and diversion tunnels. To this end, water surface profile computations, routing through diversion tunnels with variable geometric details (bend) have been included to the scope of the software.

Table 1.1 Software feature comparison (Hotchkiss et al., 2008)

	HY-8	HEC-RAS	Culvert Master	FishXing	C-PAS
Inlet and Outlet Control	✓	✓	✓	✓	✓
Water Surface Profile	✓	✓	X	✓	✓
Full Flow Option	✓	X	X	X	✓
Roadway Overtopping	✓	✓	✓	X	✓
Routing Calculations	X	X	X	X	✓
Diversion Tunnel Bending Option	X	X	X	X	✓

1.2 The Aim and Scope of the Study

In the scope of this study, a software similar to HY-8 is developed for restricted section types and other configurations by defining all the steps conducted. Also, in addition to supplement the scope of the HY-8, diversion tunnel structure analyses are added to the newly generated software. Circular and rectangular culvert sections are used for the analyses. For the tunnel structure, a circular section is defined. The software calculates the flow profile based on the given input data and provides an output using water surface profile simulation with tables having related flow values. The program is also capable of conducting design according to the local topographic and hydrologic features.

This thesis is composed of five chapters. Chapter 1 contains the introduction, aim, and scope of the study. In Chapter 2, the hydraulics of culvert and diversion tunnel structures are reviewed. The methodology followed in the thesis is described in Chapter 3, along with a description of the computer code development procedures. The application of the software is discussed in Chapter 4, while the thesis findings are delivered in Chapter 5. Appendix contains the computer code of the software.

CHAPTER 2

HYDRAULICS OF CULVERTS AND DIVERSION TUNNELS

2.1 Culverts

Culverts are the most commonly used hydraulic structures to discharge the flow from one side to the other through an embankment.

Primary function of a culvert is to convey surface water. However, it can be used to limit flow for upstream detention and minimize downstream storm runoff peaks if properly designed. The main considerations for the final selection of any drainage structure should be adequate in view of hydraulic principles, economy, and the resulting headwater effects on adjacent property (SUDAS, 2013).

2.1.1 Overview of Culverts

There are some features related to the culvert that directly affect the flow inside the barrel. The most important ones of these are shape, material, and inlet configurations.

Various cross-sectional shapes are available for both closed conduit and open-bottom culverts. The most common closed conduit shapes are circular, box (rectangular), elliptical, and pipe-arch. Circular and box culverts will be investigated throughout this study.

The shape is chosen based on construction costs, upstream water surface elevation restrictions, highway embankment height, and hydraulic performance.

The barrel roughness is related to the culvert material. The structural strength, hydraulic roughness, durability (corrosion and abrasion resistance), and

constructability all play a role in culvert material selection. Concrete (reinforced or plain), corrugated metal (aluminum or steel), and plastic (high-density polyethylene (HDPE) or polyvinyl chloride (PVC)) are the most widely used culvert materials (Schall et al., 2012). Smooth concrete material is used in the scope of this study.

Since the channel is generally wider than the culvert entrance, the culvert entrance acts as a particular form of contraction. There are many inlet configurations for the use of the culverts, and it has a direct impact on entry losses. Dead zones and entrance losses can be minimized by the appropriate selection of the inlet configuration.

The selection of various inlet configurations is based on hydraulic capacity, structural stability, aesthetics, erosion control, and fill retention (Schall et al., 2012).

In order to choose the culvert with the best features, factors, such as survey conditions, road slope, road embankment height, and natural streambed should be taken into consideration. Another process must be executed simultaneously; when designing the road, the road fill should be adjusted considering the points passing through the streambed or the culverts for drainage.

2.1.2 Culvert Hydraulics

Although a culvert is a simple hydraulic structure, obtaining flow conditions through it can be very challenging due to the changing upstream and downstream conditions, barrel characteristics, and inlet shape. These parameters create various flow conditions, but they can generally be grouped under two headings: inlet and outlet control (Schall et al., 2012).

As the culvert restricts the flow in the natural streambed, the flow outside the culvert is affected as well as the flow inside. This flow, which is limited depending on the culvert features, creates a parameter called headwater, which is the height of the accumulated water located just before the entrance and provides the energy

required for water flow. Headwater elevation can be defined as the elevation difference from the upstream surface elevation to the invert level of the culvert.

Tailwater is the depth of flow at the downstream end of the culvert, as determined from the downstream invert. Before conducting culvert hydraulic computations, tailwater elevation must be known or estimated. There are many techniques for estimating tailwater at a culvert. The height of tailwater is calculated using conventional open channel flow equations, often using normal depth approximations, and is based on the characteristics of the downstream channel at the given discharge (Creamer, 2007).

The rating curve or performance curve is a curve that gives a relationship between headwater level and the rate of flow through the culvert. To calculate the flow capacity of a culvert, the curves for both inlet and outlet control should be plotted, and the curve with the lowest discharge can be chosen when it is unclear if the control is at the inlet or at the outlet (Chaudhry, 2007).

2.1.2.1 Flow Conditions

The culvert barrel may flow full or partially full over its length. Full barrel flow is a rare condition while partially full flow governs generally. Therefore, the only way to reliably assess how much of the barrel flows full is to calculate the water surface profile.

In full flow condition, the culvert works as a pressurized closed conduit. It is also known as pressure flow. This condition only occurs if the outlet is submerged or the outlet is not submerged, but headwater is high, and the barrel is long enough (Chow, 1959).

The culvert acts as an open channel when the flow is partially full. Free surface flow can be categorized under three conditions: subcritical, critical, and supercritical. The governing flow regime is determined by evaluating the Froude number; F_r :

$$F_r = \frac{u}{\sqrt{gD_H}} \quad (2.1)$$

where u is the average flow velocity inside the culvert, g is the gravitational acceleration, and D_H is the hydraulic depth (cross-sectional area of flow / top width). Subcritical flow occurs when $F_r < 1$, the critical flow occurs when $F_r = 1$, and supercritical flow occurs when $F_r > 1$ (Chow, 1959).

An example of three flow regimes over a low spillway is presented in Figure 2.1. Subcritical flow occurs upstream of the spillway, where the velocity is low, and the flow is deep. The flow shows supercritical flow characteristics with high velocity and shallow flow depth downstream of the spillway. On the spillway crest, where the control section occurs, critical depth is expected.

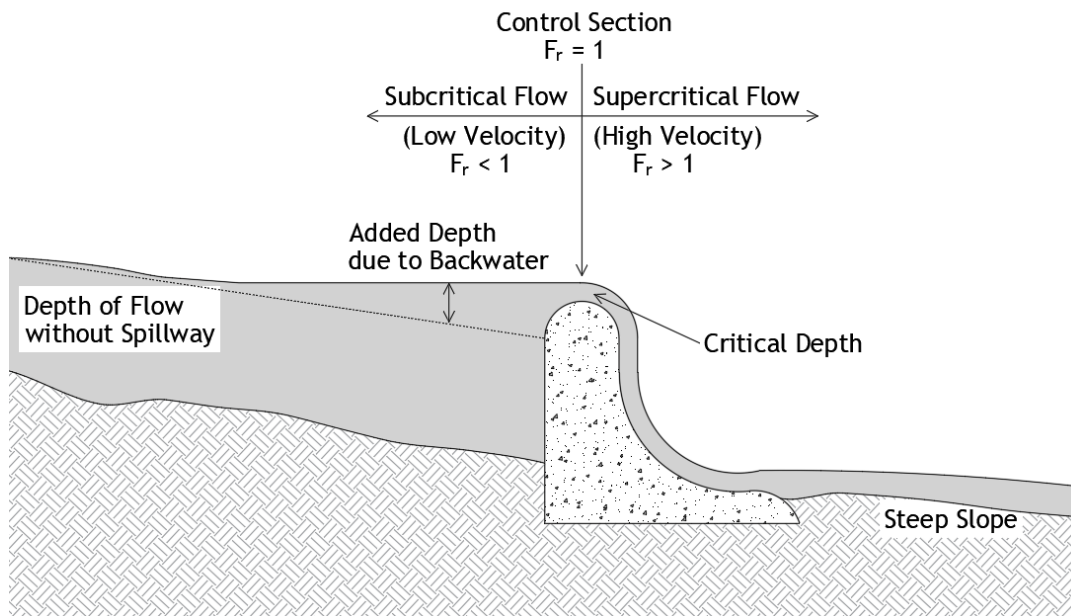


Figure 2.1 Flow types over a spillway (Schall et al., 2012)

It is essential to know if the flow type is subcritical or supercritical to conduct the free surface analysis through the culvert.

2.1.2.2 Types of Flow Control

The slope of a culvert barrel is classified as mild or steep depending on whether the depth just before the culvert begins to flow full is greater or less than the critical depth. This configuration determines where the control will be located in the culvert. According to studies conducted by Federal Highway Administration (FHWA), flow control is defined under two headings as inlet control and outlet control. Depending on whether the control is at the inlet or outlet, the behavior of the flow inside the culvert is defined (Creamer, 2007).

The inlet type of the culvert acts like a constriction, and the control section is located in this position. Critical flow depth occurs just after the culvert entrance. The flow through the culvert becomes supercritical. The properties of the culvert outlet do not affect the situation of inlet control. The parameters that affect the inlet control are inlet characteristics and flow depth just before the culvert. Figure 2.2 shows a typical inlet control section (Schall et al., 2012).

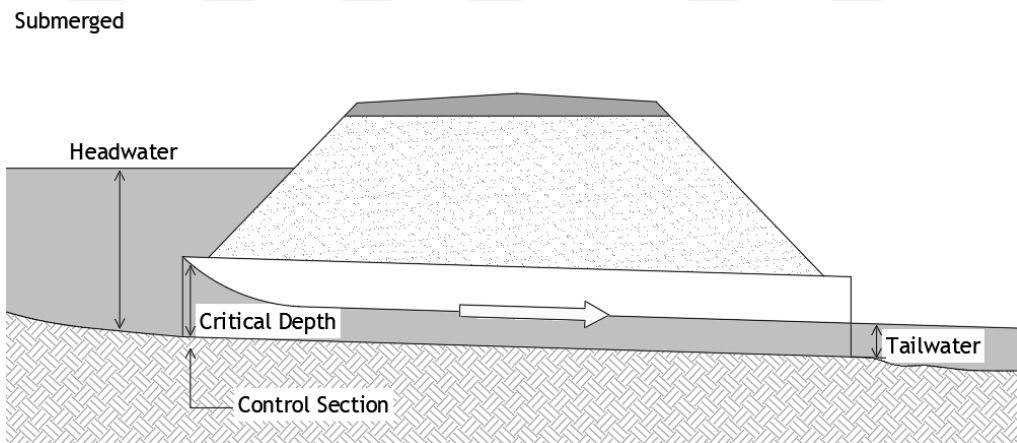


Figure 2.2 Typical inlet control section (Schall et al., 2012)

In outlet control, the culvert cannot convey the entire flow that the inlet can receive. The control section is located just before the exit, and the critical depth occurs at this point for low tailwater condition. The flow within the culvert barrel is subcritical. Figure 2.3 shows a typical outlet control section. The flow profile

parameters include all the features in the inlet control and are directly related to the barrel characteristics and tailwater elevation. These parameters can be seen in Table 2.1.

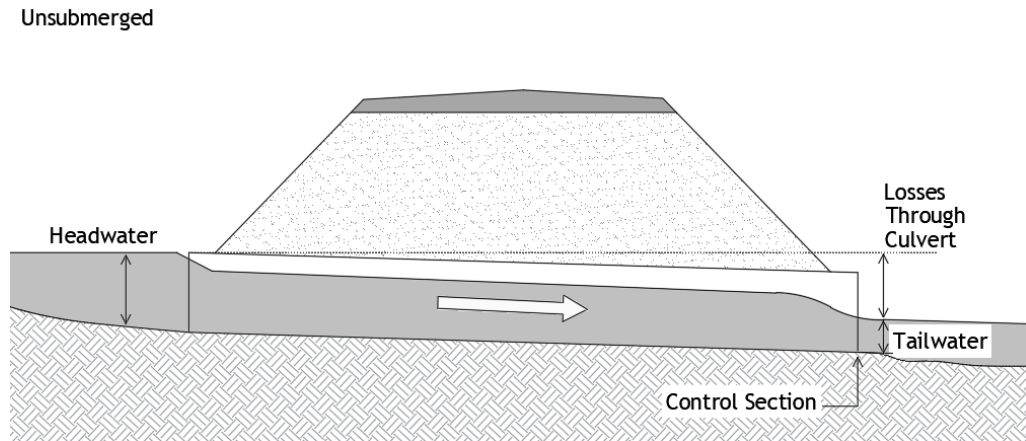


Figure 2.3 Typical outlet control section (Schall et al., 2012)

Table 2.1 Parameters affecting the control section (Schall et al., 2012)

Factor	Inlet Control	Outlet Control
Headwater	X	X
Area	X	X
Shape	X	X
Inlet Configuration	X	X
Barrel Roughness	-	X
Barrel Length	-	X
Barrel Slope	X	X
Tailwater	-	X

Note: For inlet control, the area and shape factors relate to the inlet area and shape. For outlet control, they relate to the barrel area and shape.

2.1.3 Culvert Hydraulic Design

In this section, the calculations for aforementioned conditions will be explained. The equations for culvert flow are based on the conservation of energy and mass between the approach section and a downstream section of the culvert (Fulford, 1995).

The total energy head at the upstream section 1, which is the sum of the velocity head ($u^2/2g$), pressure head (p/γ), and elevation (z), must be equal to the total head at the downstream section 2, plus the losses through the culvert H_L :

$$\frac{u_1^2}{2g} + y_1 + z_1 = \frac{u_2^2}{2g} + y_2 + z_2 + H_L \quad (2.2)$$

where u is the average velocity (m/s), g is the acceleration of gravity (m/s^2), y is the flow depth, which replaces p/γ term in open channel (m), and z is the elevation (m) above the datum in the given section.

In Figure 2.4, the energy grade line and the hydraulic grade line are presented for a full flow condition. The energy grade line represents the total energy per unit weight at a given point, while the hydraulic grade line represents the locus of points of the piezometric elevation.

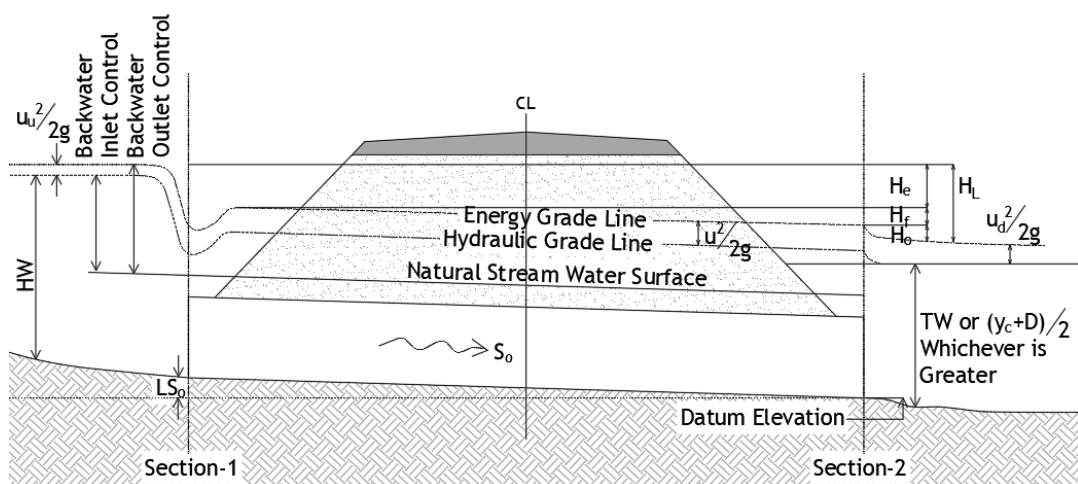


Figure 2.4 Full flow condition in a culvert (SUDAS, 2013)

However, it is not possible to express each of the flow states with a single theoretical formula, because the flow profiles involve combinations of gradually varied flow and rapidly varied flow, such as hydraulic jump. The procedure to find the flow profile in the culvert will be expressed by explaining each situation of these combinations.

In the studies carried out by the U.S. Geological Survey (USGS), the flow conditions inside the culvert are divided into six different types. Federal Highway Administration has developed these studies and gathered flow conditions under two headings: inlet and outlet control. In order to decide on the type of flow (inlet or outlet controlled), the curve giving the critical slope can be used. Derivation of this curve is described below (Yanmaz, 2021).

The critical flow velocity can be obtained from Equation 2.1,

$$u_c = \sqrt{gD_H} \quad (2.3)$$

which can be further expressed as,

$$u_c = \sqrt{g \frac{A}{T}} \quad (2.4)$$

where A is the flow area and T is the top width of the free surface in the culvert.

For a circular cross-section: $A/T = \alpha D$ where $\alpha = f(\theta \text{ or } y/D)$, θ is the central angle describing the flow depth in the culvert (Figure 2.5).

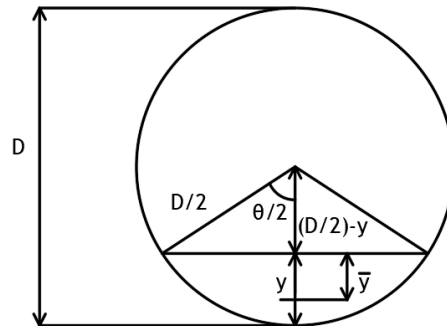


Figure 2.5 Sketch for a partially full circular section (Abo Rahma, 2015)

Flow area, A, and wetted perimeter, P, are defined by:

$$A = \frac{D^2}{8} (\theta - \sin\theta), \quad P = \frac{D}{2} \theta \quad (2.5)$$

Therefore, hydraulic radius becomes,

$$R = \frac{D (\theta - \sin\theta)}{4 \theta} = \epsilon D \quad (2.6)$$

The term $R^{4/3}$ is expressed as, $R^{4/3} = \epsilon^{4/3} D^{4/3} = \gamma D^{4/3}$

Furthermore, from Equation 2.3,

$$u_c^2 = g\alpha D = \beta D, \quad \text{where } \beta = g\alpha \quad (2.7)$$

Critical slope can be obtained from Manning's equation as:

$$S_c = \frac{n^2 u_c^2}{R^{4/3}} = \frac{n^2 \beta D}{\gamma D^{4/3}} = \frac{n^2 c_s}{D^{1/3}} \quad \text{where } c_s = \frac{\beta}{\gamma} \quad (2.8)$$

The relation between y/D and $S_c D^{1/3}/n^2$ is shown in Figure 2.6.

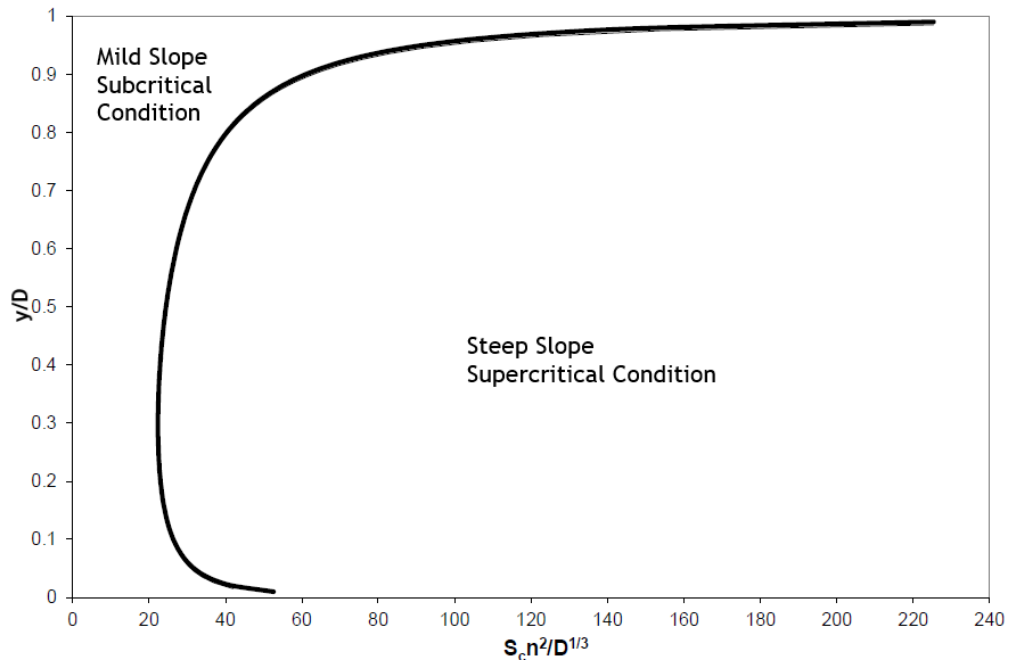


Figure 2.6 Chart for determining the type of control (French, 1987)

2.1.3.1 Inlet Control

In Figure 2.7, inlet control flow types are presented. The control is always on the inlet end of the culvert, and a hydraulic jump may occur due to high tailwater conditions.

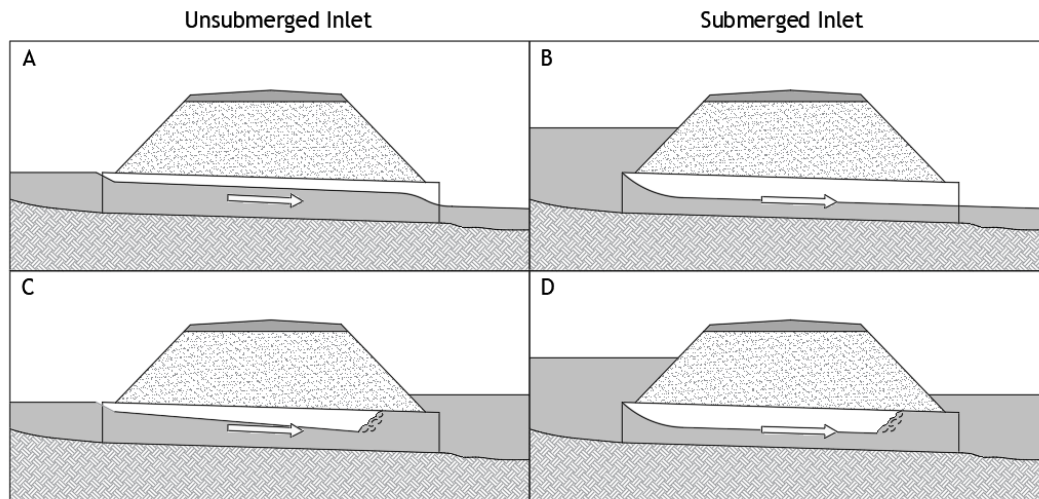


Figure 2.7 Inlet control flow types (Schall et al., 2012)

Figure 2.7.A and C indicate situations when the inlet is not submerged, and the flow passes from critical depth just downstream of the culvert entrance. The flow inside the culvert is in supercritical condition. In Figure A, the culvert flows partly full over its whole length and reaches the normal depth at the end of the barrel. In Figure C, tailwater depth is higher than the culvert barrel, which causes the flow to pass from supercritical condition to subcritical condition. This rapid change creates hydraulic jump in the culvert barrel. Hydraulic jump may also occur when the outlet is not submerged, but the tailwater depth is higher than the critical flow depth.

In Figure 2.7. B and D, culvert inlet is submerged. Just downstream of the inlet end of the culvert, the flow passes through critical depth. The flow condition is supercritical in the culvert barrel. In Figure B, the outlet end flows freely, and the culvert flows partially full over its length. The flow reaches normal depth at the end

of the barrel. In Figure D, which is an unusual condition, both the upstream and downstream ends of the culvert are submerged. Because of the rapid change in flow at the end of the barrel, a hydraulic jump occurs at this place (Schall et al., 2012).

In the case of inlet control, there are three cases that apply to the flow: unsubmerged, transition, and submerged. If the inlet is not submerged by the headwater, the culvert entrance acts as a weir, and the unsubmerged equations are used. A weir is a flow control section in which the discharge and flow depth are predictably connected to one another. If the inlet is submerged by the headwater, the flow through the entrance behaves like an orifice flow, and the submerged flow equations are used. Orifice flow describes the condition where the culvert entrance is submerged and the discharge into the entrance increases as the depth or head above the entrance increases (Creamer, 2007). These flow types can be seen in Figure 2.7.

The current and most typical methodology of performance curves for various culvert shapes was developed by the National Bureau of Standards (NBS) during the 1950s and 1960s. Equations for submerged and unsubmerged conditions were developed and enclosed a complete of four coefficients: K , M_K , C_K , and Y . Fitting curves to experimental data gathered from submerged and unsubmerged circumstances under inlet control was the goal of this method. However, one of the major drawback of this method is its difficulty to clearly identify the transition zone between inlet and outlet control. Currently, a linear transition line tangent to the inlet and outlet control curves is manually inserted as shown in Figure 2.8 (Thiele et al., 2009).

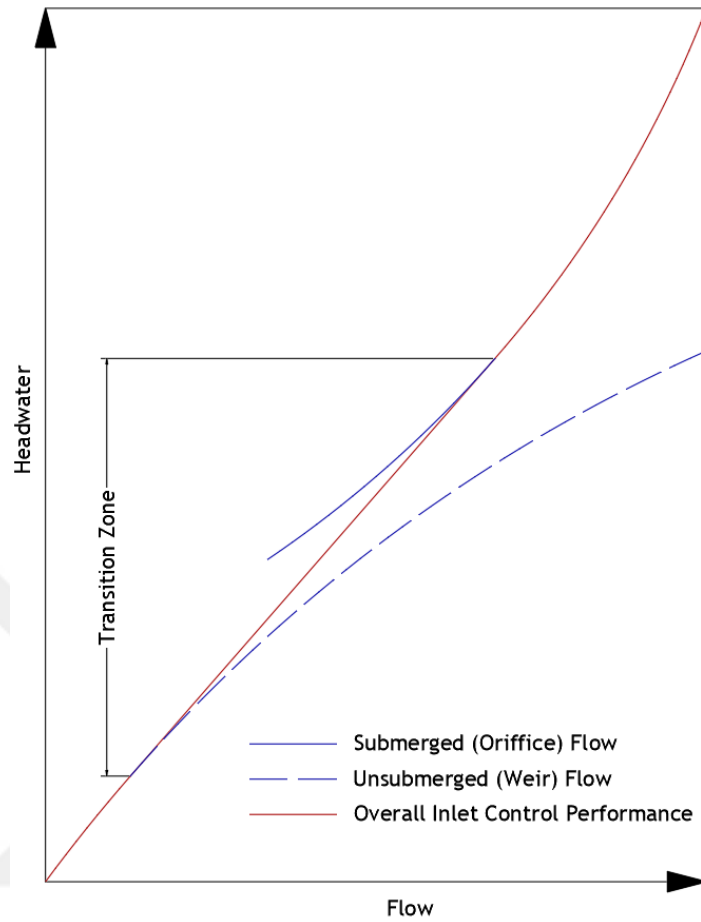


Figure 2.8 Inlet control curves (Schall et al., 2012)

2.1.3.1.1 Unsubmerged Inlet Control Equations

According to FHWA research, the equation below (Froude number defined for culvert size) is used to check if the flow is in unsubmerged condition,

$$\frac{Q}{A\sqrt{gD}} < 0.62 \quad (2.9)$$

where, Q is discharge (m^3/s), A is the inner cross-sectional area of the culvert (m^2), g is the gravitational acceleration (m/s^2), and D is the interior height of the culvert (m).

The unsubmerged condition has two forms of equations. Form I is based on theoretical background, whereas Form II has an exponential equation similar to the weir equation. Both approaches are acceptable according to the availability of data (Schall et al., 2012). Since the Form I equation is used throughout this study, only the related parameters are given in Table 2.2 for this type of flows.

$$\text{Form I. } \frac{HW}{D} = \frac{y_c}{D} + \frac{u_c^2}{2gD} + K_I \left(\frac{Q}{A\sqrt{gD}} \right)^{M_I} + K_S S_o \quad (2.10)$$

$$\text{Form II. } \frac{HW}{D} = K_{II} \left(\frac{Q}{A\sqrt{gD}} \right)^{M_{II}} \quad (2.11)$$

2.1.3.1.2 Submerged Inlet Control Equations

The submerged equation is available for the range that satisfies the following criterion,

$$\frac{Q}{A\sqrt{gD}} > 0.70 \quad (2.12)$$

$$\frac{HW}{D} = c_k \left(\frac{Q}{A\sqrt{gD}} \right)^2 + Y + K_S S_o \quad (2.13)$$

where,

HW: Headwater depth at the inlet end (m)

D: Interior height of the barrel (m)

y_c : Critical depth (m)

u_c : Velocity at critical depth (m/s)

K_S : Slope coefficient (0.7 for mitered inlets, -0.5 for unmitered inlets.)

S_o : Culvert slope (m/m)

K_I , M_I , Y , c_K : Empirical constants (Table 2.2)

Commonly used K_I , M_I , c_K , Y coefficients in practice are summarized in Table 2.2.

Table 2.2 Inlet control constants (for concrete material) (Schall et al., 2012)

Shape	Inlet Edge	K_I	M_{KI}	c_k	Y
Circular	Square edge with headwall	0.3155	2.0	1.2816	0.67
Circular	Groove end with headwall	0.2512	2.0	0.9402	0.74
Circular	Groove end projecting	0.1449	2.0	1.0207	0.69
Rectangular	30-750 Wingwall Flares	0.1475	1.0	1.1173	0.81

2.1.3.2 Outlet Control

Figure 2.9 represents the outlet conditions. For all the conditions, control is on the outlet section or downstream. The type of flow profile depends on the submergence of the inlet and outlet of the barrel. When the barrel is not full for the partially full condition, the flow is in subcritical state.

In Figure 2.9.A and C, where the inlet and the outlet are unsubmerged, the culvert flows partially full over its length, and the flow is in subcritical condition. In Figure A, tailwater depth is lower than the critical depth, while in Figure C, tailwater is higher. The higher depth governs the outlet velocity of the barrel. This situation will be examined in the following sections.

In Figure 2.9.B, the inlet is submerged, and the outlet is unsubmerged. The flow in the culvert is considered as pressurized flow over a certain distance. At the outlet

end of the culvert, flow passes from critical depth or tailwater depth, whichever one is higher. Figure 2.9.D represents the full flow condition when the inlet and the outlet are submerged simultaneously. Pressure flow occurs inside the barrel. This condition is considered as the ideal solution and used in all the nomograms developed by FHWA.

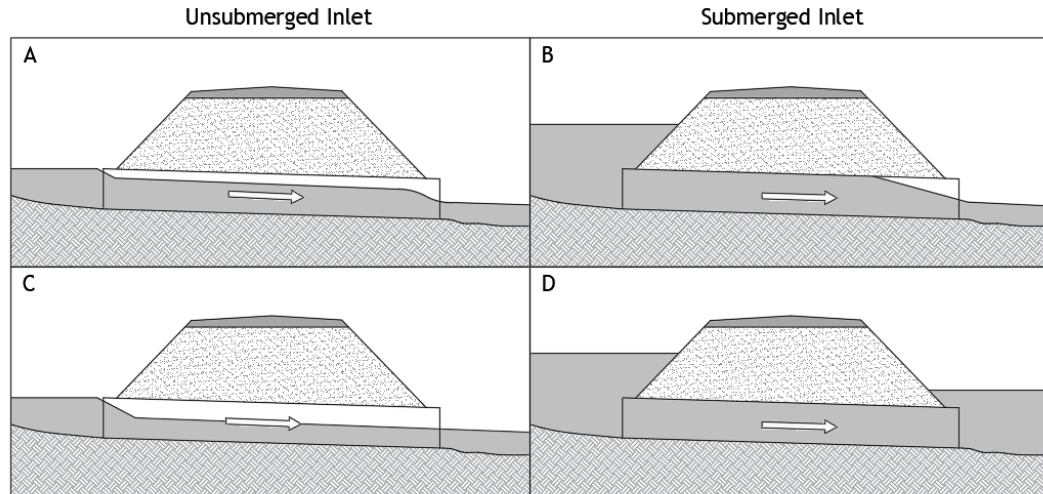


Figure 2.9 Outlet flow types (Schall et al., 2012)

The factors influencing the outlet control are indicated in Table 2.1. Barrel roughness is related to the material type used. The nature of the material affects the performance of the flow. The roughness of the material is expressed by the Manning's roughness coefficient. The barrel slope is mostly the same as the natural stream slope, but it also depends on the elevation of the road passing over it. The slope determines the flow profile inside the barrel by affecting the velocity and the flow condition. The distance from the inlet end to the outlet end is the barrel length. The length governs the friction loss between the inlet and outlet. Barrel area is a function of the barrel dimensions, and barrel shape is a function of the culvert type. (Schall et al., 2012).

In case of the outlet control, there are two types of flow to be examined: full flow and partially full flow conditions.

2.1.3.2.1 Full Flow Condition

In this condition, the flow in the culvert barrel acts as a pressure flow and depends on the conservation of energy (Figure 2.10). The total loss (H_L) that provides the flow of water is the sum of entrance loss (H_e), friction loss (H_f), and outlet loss (H_o). In addition, other special losses (normally expected in case of tunnel flow) need to be considered if valid for the condition, such as bending loss (H_b), junction loss (H_j), etc.

$$H_L = H_e + H_f + H_o + H_b + H_j \quad (2.14)$$

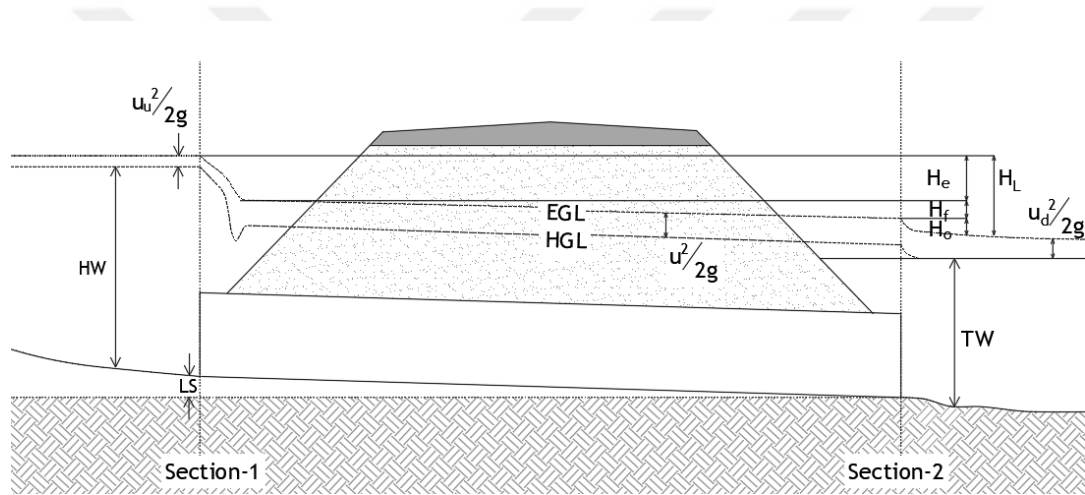


Figure 2.10 Full barrel condition (Schall et al., 2012)

The entrance loss is a function of the velocity head,

$$H_e = K_e \frac{u^2}{2g} \quad (2.15)$$

where u is the average velocity in the culvert barrel (m/s), and K_e is the entrance loss coefficient indicated in Table 2.3 based on different inlet configurations.

Table 2.3 Entrance loss coefficients (Schall et al., 2012)

Type of Structure and Details of Entrance	Coefficient K_e
• Pipe, Concrete	
Projecting from fill, socket end (groove-end)	0.2
Projecting from fill, squared cut end	0.5
Headwall or headwall and wingwalls, socket end of pipe (groove-end)	0.2
Headwall or headwall and wingwalls, square edge	0.5
Rounded (Radius = $D/12$)	0.2
Mitered to conform to fill slope	0.7
End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels or Side- or slope-tapered inlet	0.2
• Pipe, or Pipe-Arch. Corrugated Metal	
Projecting from fill (no headwall)	0.9
Headwall or headwall and wingwalls square-edge	0.5
Mitered to conform to fill slope, paved or unpaved slope	0.7
End-Section conforming to fill slope	0.5
Beveled edges, 33.7° or 45° bevels	0.2
Side or slope tapered inlet	0.2
• Box, Reinforced Concrete	
Headwall parallel to embankment (no wingwalls)	
- Square-edged on 3 edges	0.5
- Rounded on 3 edges to radius of $D/12$ or $B/12$ or beveled edges on 3 sides	0.2
Wingwalls at 30° to 75° to barrel	
- Square-edged at crown	0.4
- Crown edge rounded to radius of $D/12$ or beveled top edge	0.2
Wingwall at 10° to 25° to barrel (Square-edged at crown)	0.5
Wingwalls parallel (extension of sides), square-edged at crown	0.7
Wingwalls parallel (extension of sides), side- or slope-tapered inlet	0.2

Friction loss is also a function of velocity head which can be found by Manning's equation,

$$H_f = \frac{u^2 n^2 L}{R^{4/3}} \quad (2.16)$$

where n is the Manning's roughness coefficient, L is the length of the barrel (m), and R is the hydraulic radius of the culvert barrel (m).

The exit loss is a function of the velocity head difference at the outlet. Since the energy balance is valid for the pressurized flow, the outlet end is accepted as submerged, and outlet velocity is usually neglected. Therefore, for sudden expansion at the outlet, K_{exit} is assumed to be 1.

$$H_o = K_{\text{exit}} \frac{u^2}{2g} \quad (2.17)$$

The head loss for the bending culvert can be obtained by Equation 2.18.

$$H_b = K_b \frac{u^2}{2g} \quad (2.18)$$

where K_b is the bending loss coefficient. Values of K_b can be taken from Table 2.4 as a function of the radius of the curvature of the bend (R_c), divided by the culvert diameter. For non-circular culvert, the following relation needs to be used,

$$D_{\text{eq}} = \sqrt{\frac{4A}{\pi}} \quad (2.19)$$

where A is the cross-sectional area of the culvert.

Inserting all the losses indicated above into equation 2.14, the following equation is obtained:

$$H_L = \left(1 + K_e + \frac{n^2 L}{R^{4/3}} \right) \frac{u^2}{2g} \quad (2.20)$$

Table 2.4 Loss coefficients for gradual bends in conduits flowing full (Malone and Parr, 2008)

R_c/D_{eq}	K_b		
	90°	45°	22.5°
1	0.5	0.37	0.25
2	0.3	0.22	0.15
4	0.25	0.19	0.12
6	0.15	0.11	0.08
8	0.15	0.11	0.08

If the energy equation is written between the upstream and downstream of the culvert barrel, as shown in Figure 2.10, the following equation is obtained:

$$HW + LS + \frac{u_u^2}{2g} = TW + H_L + \frac{u_d^2}{2g} \quad (2.21)$$

where, HW is the headwater depth at the entrance for the outlet control (m), LS is the height difference through the culvert (m), u_u is the upstream velocity (m/s), TW is the tailwater depth (m), H_L is the sum of all losses, and u_d is the downstream velocity (m/s).

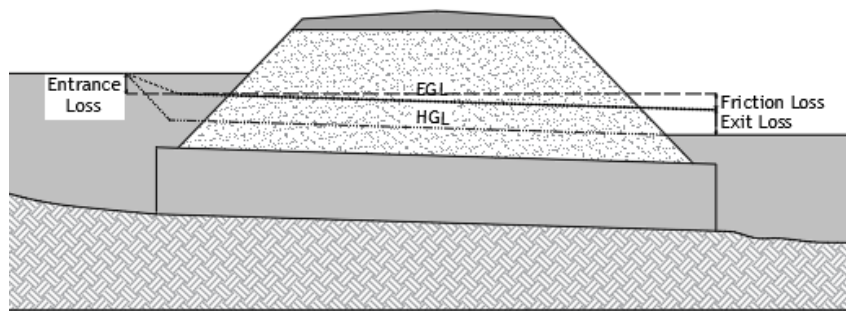
For the full flow condition, the upstream and downstream velocities are very low, and in most instances, neglected. So, the equation takes the following form:

$$HW = TW - LS + \left(1 + K_{ent} + \frac{2gn^2L}{R^{4/3}}\right) \frac{Q^2}{2gA^2} \quad (2.22)$$

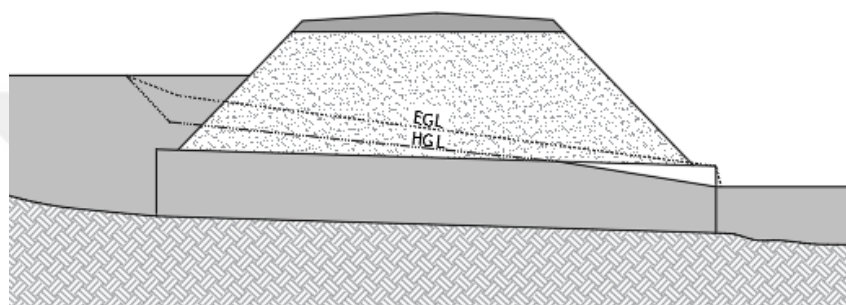
2.1.3.2.2 Partially Full Flow Condition

Equations obtained above for the outlet control are valid for the full barrel flow. However, when the barrel is subject to partially filled conditions, backwater calculations should be carried out (See Figure 2.11.C).

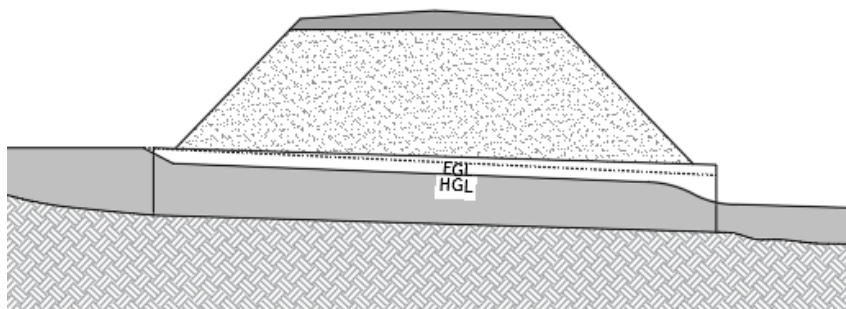
A. Full Flow



B. Partially Full Flow



C. Free Surface Flow



D. Hydraulic Grade Line Approximation

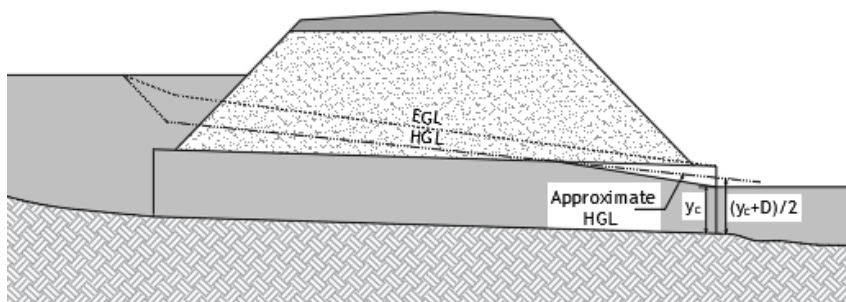


Figure 2.11 Outlet control flow profiles (Schall et al., 2012)

Figure 2.11.A represents the full barrel flow mentioned in the previous section. The equations are also valid for Figure 2.11.B since the flow is almost full. However, for the free surface flow represented in Figure 2.9.A and C, computations need to be carried out as gradually varied flow by the backwater flow calculations. The procedure starts from the outlet end of the culvert with the critical depth or tailwater depth, whichever is higher, and is carried out until the inlet end with gradually varied flow equations.

If the predicted backwater profile touches the top of the barrel, a straight, full flow hydraulic grade line extends from that point to the culvert entrance, as shown in Figure 2.11.B. This procedure is proposed by FHWA.

Backwater calculations can be time-consuming and challenging. An approximate method has been developed by FHWA to eliminate these efforts. According to this approach, it is appropriate to start the hydraulic grade line from $(y_c+D)/2$ at the exit and extend it straight up to the inlet entrance. If the tailwater depth is greater than $(y_c+D)/2$, the tailwater depth is used as a starting section. This approach gives reliable results for end depth greater than $0.75D$ (Schall et al., 2012).

The approximate method works best when the barrel is almost full. However, if the barrel is partially full over its length, the accuracy of this method decreases. In the scope of this study, backwater calculations are used for the partially full flow over the total length, and the approximate method is used for the barrel flows full over at least part of its length. As an alternative option, direct step method is also applied in this study to determine the location of the full flow with respect to the end section with the selected tailwater elevation.

2.1.3.3 Outlet Velocity

Determination of outlet velocity at culvert exit is important for the decision making in scour resistant toe design. Culverts typically result in higher velocity than natural stream velocities.

In most circumstances, the exit flow velocity at the end of the culvert barrel section is determined by the culvert geometry, including the barrel slope, as well as upstream and downstream channel parameters (Szpakowski, 2014).

For the inlet control, full flow is assumed at the outlet for the culvert flow types depicted in Figures 2.7.C and D. The complete barrel area is used to determine the outlet velocity. Normal depth is assumed at the culvert outlet for the culvert flow types depicted in Figure 2.7.A and B and the outlet velocity is calculated using Manning's equation. Gradually varied flow calculations may be needed to find the location of the normal depth along the barrel (Thompson and Kilgore, 2006).

In outlet control, outlet velocity depends on the cross-sectional area of the flow at the outlet end. If the tailwater depth is lower than the critical depth, tailwater depth is used to find outlet velocity. If the tailwater depth is higher than the critical depth but lower than the barrel height, tailwater depth is used for outlet velocity. If the tailwater depth is higher than the barrel height, barrel height is used to find outlet velocity (Schall et al., 2012).

2.1.3.4 Storage Routing

Routing is the procedure of determining the outflow hydrograph from a conduit by transposing an inflow hydrograph through it. The method of evaluating the effect of transient upstream ponding induced by the backwater of the culvert is known as flood routing through a culvert. It is probable that the results of culvert analyses will be conservative if flood routing is not taken into account (Gross et al., 2019). This will be verified in Chapter 4 (See Table 4.56).

A flood hydrograph is attenuated by a large storage capacity behind a highway embankment. The needed capacity of the culvert, as well as its size, may be decreased significantly as a result of the lowered peak discharge associated with this attenuation. If there will be extensive storage behind a culvert, the design should be double-checked by running the design hydrographs through the culvert to

determine the discharge and stage. Storage should only be considered if the storage area will be available throughout the lifetime of the culvert (Schall et al., 2012).

The storage concept can be explained through Figure 2.12. The vertical axis represents the flow rate, while the horizontal axis represents the time. Any portion of the area on the graph multiplied by time gives the volume. The area under the inflow hydrograph is the volume of flow entering the culvert. The area under the outflow hydrograph is the volume leaving the culvert. The area between the two curves represents the volume of flow accumulated in the barrel. Since the amount of flow entering and leaving is the same throughout the flood, the areas under the inflow and outflow hydrographs are equal to each other (Schall et al., 2012).

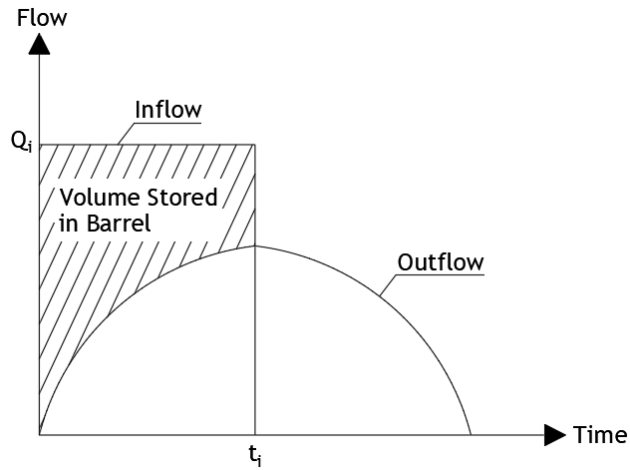


Figure 2.12 Culvert routing inflow and outflow hydrographs (Schall et al., 2012)

Conservation of mass (continuity equation or storage equation) can be written as follows:

$$\frac{\Delta S}{\Delta t} = \frac{I_1 + I_2}{2} - \frac{Q_1 + Q_2}{2} \quad (2.23)$$

where, $\Delta S/\Delta t$ is the rate of storage change, I is the inflow discharge and Q is the outflow discharge. Assuming that the change in I and Q is linear along time interval Δt :

$$\left(\frac{I_1 + I_2}{2} - \frac{Q_1 + Q_2}{2}\right) \Delta t = \Delta S \quad (2.24)$$

The subscript 1 and 2 represents the beginning and end of the time interval. Since there are two unknowns (Q_2 and S_2), the equation can be rearranged to separate the known values and unknown values at the left and right sides of the equality, respectively:

$$\left(\frac{I_1 + I_2}{2}\right) + \left(\frac{S_1}{\Delta t} + \frac{Q_1}{2}\right) - Q_1 = \left(\frac{S_2}{\Delta t} + \frac{Q_2}{2}\right) \quad (2.25)$$

The routing procedure requires three inputs to solve this equation: inflow hydrograph, discharge-elevation relationship, and area-elevation relationship. These parameters need to be obtained according to the survey area and culvert features (Brown et al., 2013). This procedure requires an iterative solution, as the unknown values depend on the previous value of the hydrographs. Iterations are continued until the output hydrograph is achieved. This procedure will be explained in detail in the methodology chapter.

2.2 Diversion Tunnels

The diversion structures are a set of structural components that ensure that the river can bypass the dam site while the main structure is being built. The primary purpose of the diversion facility is to protect and ensure the safety of the construction site.

The river diversion can take a variety of forms. It should be emphasized that the preliminary investigation of the hydrological properties of the watershed and the morphological features of the location precedes the design of the river diversion (Silva, 2013).

As river diversion structures can be found in many different types, decision-making for optimum selection of them is based on comparison of their cost and feasibility.

The following concepts should be analyzed to choose the best solution (USBR, 1987):

- Characteristics of streamflow
- Size and frequency of diversion flood
- Methods of diversion
- Specifications requirements

The river diversion tunnel is the most expensive option, and it is usually applied only when other options are unavailable. In the execution of tunnel feasibility study, the geotechnical characteristics of the implantation site are critical. This sort of river diversion is frequent in valleys, regardless of the dam type, and as previously said, it is considered when other options are difficult to implement and may result in higher costs (Silva, 2013).

The diversion tunnel serves to discharge the flow in the streambed and can be found in many different sections. The most used types are circular and horseshoe in cross-section. (Vischer and Hager, 1998). The circular section will be considered throughout this study.

The diversion through the tunnel can be in the state of free surface flow or pressurized flow. In most cases, the flow is in a free surface state and should not exceed 70% of the tunnel capacity to avoid greater velocities (Silva, 2013).

Various water surface profiles may occur throughout the tunnel. The flow state must be known to obtain where the flow reaches the uniform depth or where hydraulic jump occurs, if any. The tunnel structure can be conceivable as a long span culvert. In the software HEC-RAS developed by USACE, the diversion tunnel is modeled as a culvert structure (Indrawati et al., 2018).

Since the tunnel structure operates as a long span culvert, all the flow conditions that are mentioned in the culvert section are also valid for a tunnel structure. For this reason, flow conditions through tunnels will not be repeated once more.

CHAPTER 3

DEVELOPMENT OF THE COMPUTER CODE

3.1 General Information

The principal aim of this study is to develop a computer program that can perform flow analysis in a culvert and diversion tunnel under different hydraulic conditions. In this context, information about required hydraulic conditions and their effects on the flow profiles in the culvert and the diversion tunnel are given in the subsequent parts of the thesis.

The calculations for determining a flow profile can be quite lengthy and complex. With a desktop application called C-PAS, which is developed in the scope of this thesis, it is aimed to reveal the flow profile in the culvert and the diversion tunnel under certain hydraulic conditions in a fast and efficient manner.

C-PAS desktop application is developed using C# programming language, which is one of the most popular programming languages developed by Microsoft and used in coding desktop applications. While coding the program, the visual design environment on Visual Studio named WPF (Windows Presentation Foundation) was applied, which is used in the coding of detailed applications, provides the user with the opportunity to make visual interventions at every stage, and can be performed more successfully and easily than WinForms applications, which are alternative to data binding operations.

The codes of C-PAS desktop application are included in the appendix part of the thesis.

This application accepts the parameters depending on the hydraulic conditions specified in the next subtitle as input and performs flow analysis within the culvert

or diversion tunnel. The outputs of this program are in the form of a table containing the water elevation values at the inside, entrance and exit of the structure, routing through the conduit and a visual presentation showing the flow profile (See Figure 3.1).



Figure 3.1 Software interface

3.2 Inputs of the Software

In order to determine the flow profile using the software, some inputs must be given initially by the user:

- Section type
- Design discharge or any discharge for analysis purpose
- Inlet type
- Culvert or tunnel geometry (culvert diameter or bottom width and height, culvert or tunnel length)
- Slope of the conduit
- Manning's roughness coefficient for the conduit
- Tailwater depth
- Downstream invert elevation (outlet elevation)
- Bending parameters (angle and radius of bend)
- Roadway parameters (crest length and crest elevation)

There is also routing option in the software and some information is needed to be entered for routing calculations, such as:

- Δt , time interval
- I_p , peak inflow rate
- t_p , time to peak
- Reservoir volume at t_0
- a, b, c (coefficients of the polynomial expression used for defining the area-elevation relation of the upstream pond)

As shown in Figure 3.1, these inputs can be seen on the main window.

3.3 The Flowchart

The flowchart of the software is given in Figure 3.2. After the data entrance, the first step is to calculate the normal and critical depths according to the section type, as shown in the figure. Then S_c Curve graph is used to decide on the type of flow inside the culvert. The percent fullness in the culvert is also obtained from this chart.

If the inlet control governs, gradually varied flow calculations are initiated from the upstream end of the culvert to reach the normal depth inside. Also, it is needed to check the tailwater depth if the outlet is submerged or not submerged. Additional information for whether or not the tailwater depth is higher than the critical depth is also required. According to this situation, a hydraulic jump calculation may be needed at the downstream end.

If the outlet control governs, it is necessary to check whether the culvert operates as a pressurized flow or partially full flow to generate the water surface profile. Backwater calculations may be required for the partially full flow conditions.

After these steps, headwater elevations are determined according to the governing flow. If the inlet control is valid, three flow states must be checked mentioned in the previous chapter, i.e., submerged, transition, or unsubmerged upstream conditions.

The outlet control headwater elevation is related again to the fullness of the flow. If the culvert flows full, the headwater is obtained by the conservation of energy. If the partially full flow governs, backwater calculations are used to reach the headwater.

Also, with data entry for the road parameters, a realistic water surface profile simulation is obtained after these calculations.

For the routing procedure, which is another output of the software, the inflow hydrograph is plotted according to the parameters entered. Outlet hydrograph is obtained with the routing calculations.

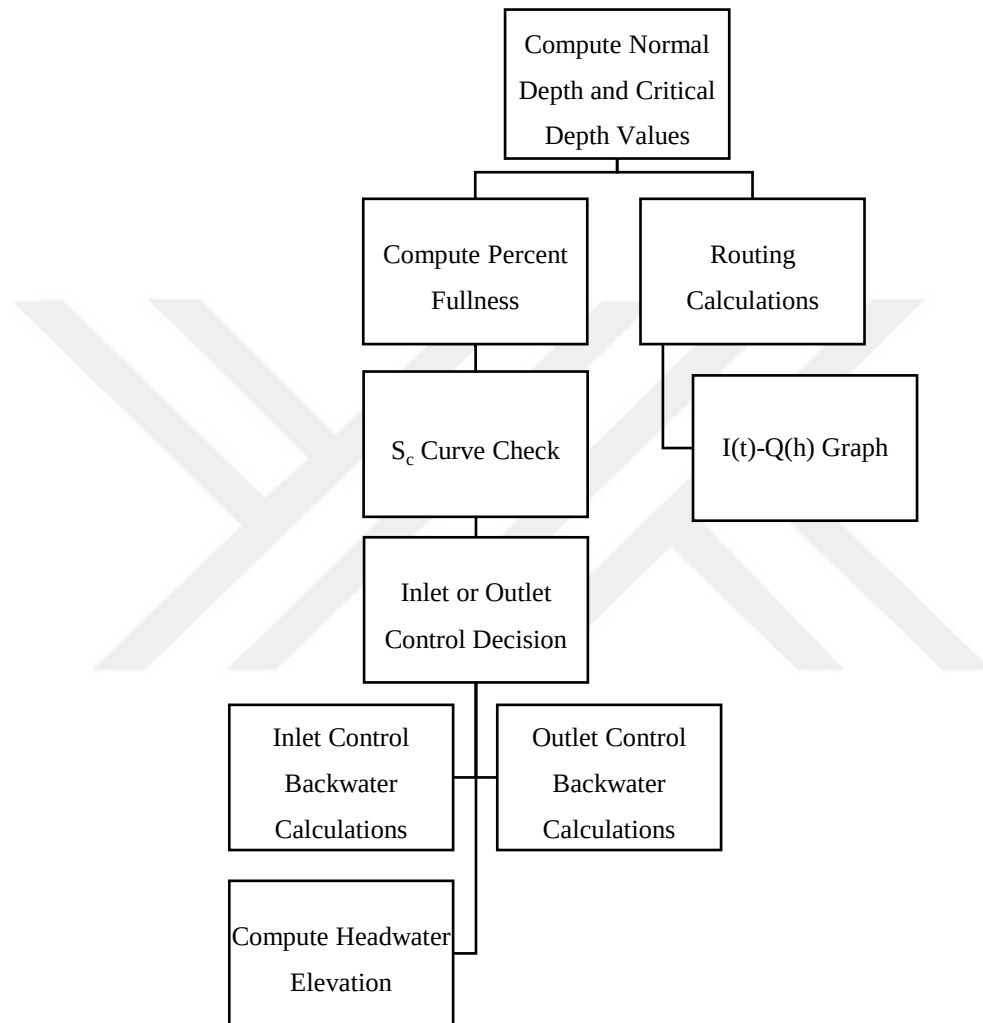


Figure 3.2 The flowchart

3.4 The Methodology

All the calculations were handled with Microsoft Excel first and then coded with C# software. The calculations will be described in detail and an example solution will be presented for each parameter.

3.4.1 Estimation of Flow Control

According to the selected section type, the normal depth is found by the Manning equation. Critical depth is also computed with respect to the culvert geometry. Since it is needed to use the area and wetted perimeter, geometrical properties of a circle and rectangle are used to find the critical and normal depths.

This procedure requires an iterative solution. First, a random value is assigned to the normal depth (y_n) and critical depth (y_c) values. These depths are increased or decreased by 0.0001 m until the computed discharge is equal to the given discharge.

After obtaining the flow depths, the percent fullness of the culvert is determined. The software calculates the " $S_c D^{1/3}/n^2$ " value to check the percent fullness range to identify the type of control (See Figure 2.5).

3.4.2 Gradually Varied Flow Calculations

Direct Step Method is an efficient solution to calculate water surface profile for a culvert flowing partially full. It is used to obtain gradually varied flow profiles at increments of known depths (Zaghloul and Darwish, 1987). For the application of the Direct Step Method, channel profile is shown in Figure 3.3 in which α_e stands for energy correction coefficient. In this study α_e is accepted to be unity.

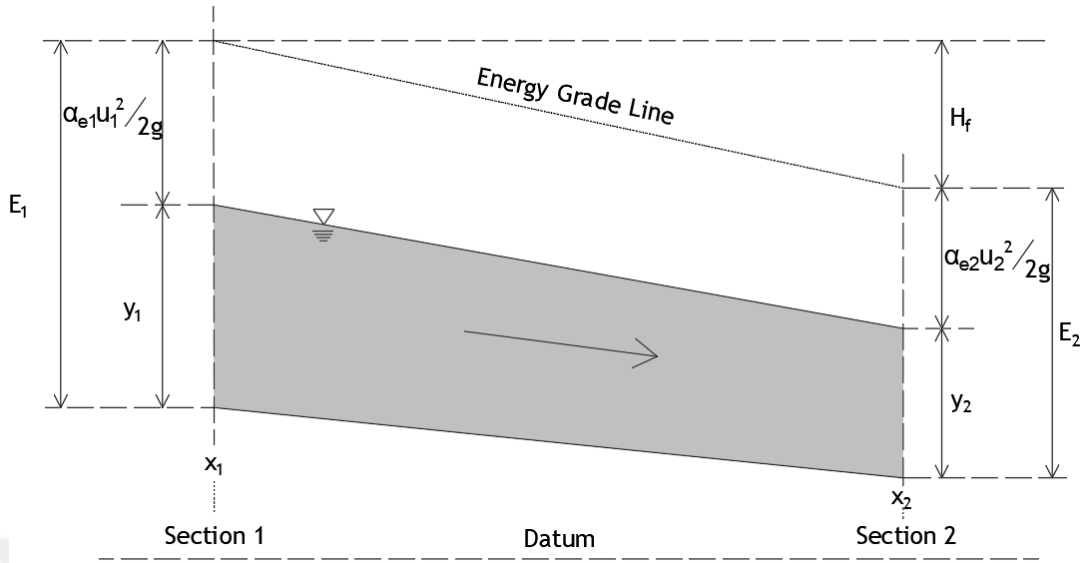


Figure 3.3 Channel reach for computation of direct step method (Chaudhry, 2007)

The total head can be shown as:

$$H = z + y + \frac{Q^2}{2gA^2} = z + E \quad (3.1)$$

where E is the specific energy for indicated section. If the derivative of H with respect to x is taken, the coordinates of the water surface profile can be found:

$$\frac{dH}{dx} = \frac{dz}{dx} + \frac{dE}{dx} = \frac{dz}{dx} + \frac{dE}{dy} \frac{dy}{dx} \quad (3.2)$$

By replacing dy/dx by the finite differences (Yanmaz, 2018):

$$\frac{\Delta y}{\Delta x} = \frac{S_o - S_f}{1 - F_r^2} \quad (3.3)$$

For reducing the error induced by the replacement of dy/dx by $\Delta y/\Delta x$, the term Δy is selected as a relatively small value, i.e., 0.01 m.

Water surface profile in a culvert for the inlet control can be analyzed under two headings depending on whether the tailwater depth is higher than the normal depth or not. If the outlet end is not submerged or the tailwater depth is lower than the

critical depth, the water surface profile connects to tailwater from normal depth. The gradually varied flow calculations are only carried out in the inlet part. Calculations start with the critical depth at the inlet end and continue with 0.01 m drops until reaching the normal depth.

If the inlet control governs and the outlet end is submerged, or the tailwater depth is higher than the critical depth, the hydraulic jump will occur in the culvert barrel, as stated in Section 2.1.3.1. The energy is lost through the turbulence that occurred through the hydraulic jump, but the momentum is conserved on either side of the jump (*HY-8 User Manual*, 2016). A definition sketch describing hydraulic jump is shown in Figure 3.4 in which F is the specific force.

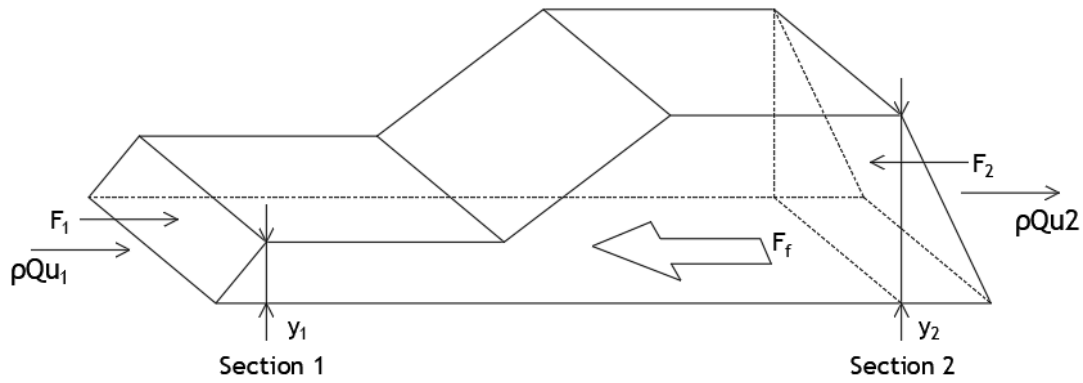


Figure 3.4 Hydraulic jump in horizontal channel (Thompson and Kilgore, 2006)

To determine the place and the length of the hydraulic jump, C-PAS calculates the flow depths by direct step profile computation with the increment of 0.01 m on both ends: starting with critical depth from the upstream end to the downstream for supercritical flow and starting with tailwater depth from the downstream end to the upstream for subcritical flow. The specific force is found for all these flow depths.

For an arbitrary channel shape with a horizontal floor, the generic version of the momentum equation can be utilized to solve the hydraulic jump sequent-depth connection. The conservation of momentum through the hydraulic jump involves:

$$\frac{Q^2}{gA_1} + A_1\bar{y}_1 = \frac{Q^2}{gA_2} + A_2\bar{y}_2 \quad (3.4)$$

where, Q is the discharge (m^3/s), A is the cross-sectional area for sections 1 and 2 as shown in Figure 3.4 (m^2) and $\bar{y}$ is the distance from the water surface to the centroid of the cross-sectional area (m) (Thompson and Kilgore, 2006).

The momentum equation indicated above cannot be used directly in sloped channels since the weight of the water should be considered. This volume may be neglected for slopes less than 10 percent and the jump can be analyzed as if it occurs on a horizontal channel (Thompson and Kilgore, 2006). In the scope of this study, culvert slopes are used below 10 percent.

C-PAS calculates the specific forces along the two directions (upstream and downstream) and compares them until the two specific forces equalize. Hydraulic jump is accepted to occur at that section. In Figure 3.5, F_1 and F_2 are the specific forces at both sides of the jump. For the horizontal conduit, hydraulic jump length is calculated as follows (*HY-8 User Manual*, 2016):

$$\text{For circular section } L_j = 6y_2 \quad (3.5)$$

$$\text{For rectangular section } L_j = 220y_1 \left(\tanh \left(\frac{F_{r1} - 1}{22} \right) \right) \quad (3.6)$$

where, L_j is the length of the hydraulic jump (m), y_1 is the initial depth of the jump, F_{r1} is the Froude number of supercritical flow depth and y_2 is the sequent depth of the jump.

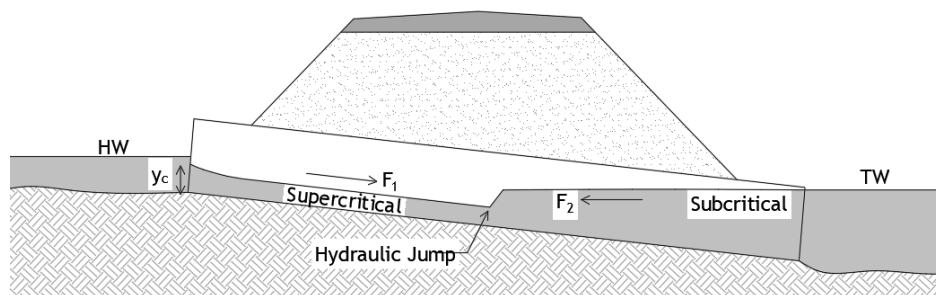


Figure 3.5 Hydraulic jump location (*HY-8 User Manual*, 2016)

In the outlet control, tailwater elevation determines the starting depth for the gradually varied flow calculations which start from the downstream end and with an increment of 0.01 m proceed until the upstream. There exist two calculations for partially full flow condition (Figure 3.6):

- Critical depth is used if the tailwater is lower than critical depth.
- Tailwater depth is used if the tailwater is higher than the critical depth but lower than the barrel height.

If the hydraulic grade line intersects with the top of the barrel, then water surface profile continues along the barrel height until the headwater.

For the full flow condition:

- If the tailwater depth is higher than the barrel height, culvert works as a closed conduit. Barrel height is used to find outlet velocity. Flow profile calculations are not executed, only headwater and tailwater depths are shown.

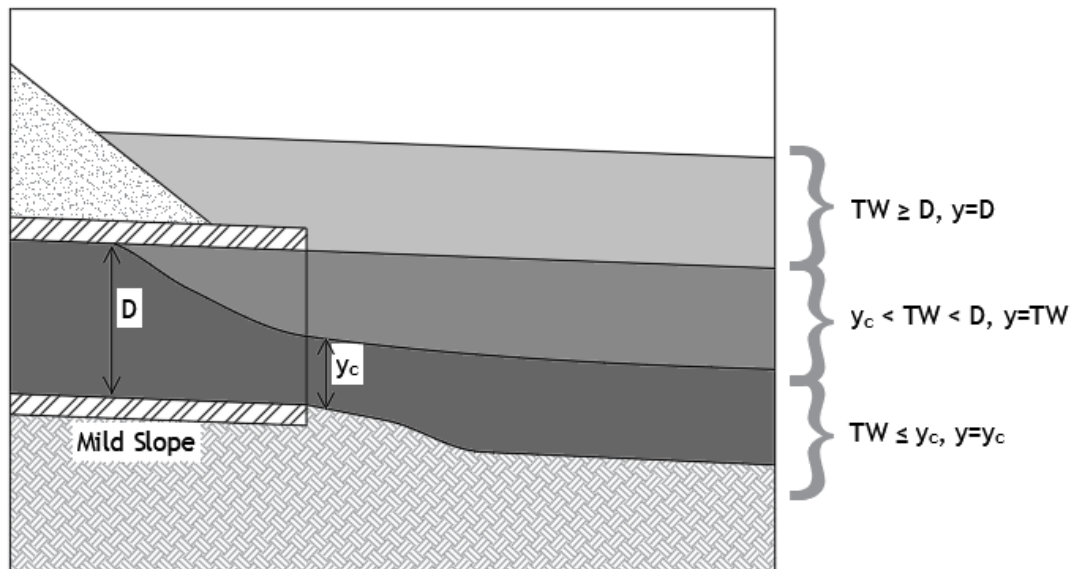


Figure 3.6 Outlet control tailwater condition (Schall et al., 2012)

3.4.3 Headwater Estimation

Headwater formulas have already been introduced previously. In inlet control, these formulas are used depending on the selection of input data and critical and normal depth values are then computed.

C-PAS uses the conservation of energy to find the headwater elevation for the culvert flowing full. Also, the software uses the same equation for the full flow most of the barrel length. Only the decision is made according to use of the highest one: tailwater depth or $(D+y_c)/2$. This value is considered in Equation 2.22.

For the conditions that flow partially full over its length, the software checks the higher value of tailwater or critical depth. Once the starting depth is computed, direct step calculations proceed along the culvert length with an increment of 0.01 m. When the calculations reach to the upstream end, the entrance losses are added to obtain the headwater elevation.

3.4.4 Routing Calculations

The first step in routing calculations is the formation of a mathematical expression for inflow hydrograph. In the routing process culvert type, size, and operation, as well as the reservoir volume come into picture. When routing is used for design purpose, it leads to determination of culvert characteristics. Routing can also be utilized for the analysis of flow conditions and upstream water level during the passage of a particular flood.

Depending on the size of the reservoir, reservoir flood routing can be performed using appropriate approaches with the time step Δt (Novak et al., 2007).

C-PAS works with some parameters that should be given. The inflow hydrograph, area-elevation equation, and outflow-elevation relationship are defined in a standard way according to the parameters depending on the characteristics of the culvert. The following inflow hydrograph based on Horn (1987) approach is used.

$$I(t) = I_p \left(\frac{t}{t_p} \right)^{3.5} \exp \left(-3.5 \left(\frac{t}{t_p} - 1 \right) \right) \quad (3.7)$$

where $I(t)$ is the inflow hydrograph, I_p is the peak inflow rate, t is the time, and t_p is the time to peak. The values of I_p and t_p are determined using hydrologic information and introduced as inputs.

The area-elevation relation is assumed to have the following form:

$$A(H_r) = aH_r^3 - bH_r^2 + cH_r \quad (3.8)$$

where $A(H_r)$ is the surface area of the upstream pond at any elevation H_r , which is measured from the axis of the culvert at its entrance. The coefficients a , b , and c are defined by the user according to the topographic features of the area concerned.

The outflow relation is explicitly expressed as:

$$Q(H_r) = \sqrt{\left(H_r - TW + \frac{S_0 L}{\left(K_{\text{exit}} + K_{\text{ent}} + \frac{2gn^2 L}{R^{\frac{4}{3}}} \right)} \right)} 2gA^2 \quad (3.9)$$

Step 1. Time for inflow is written.

Step 2. Computational time interval between two successive inflows is written.

Step 3. Instantaneous inflow, I , is written.

Step 4. Average of the two successive inflows is computed.

Step 5. Volume of water introduced to conduit is computed by $V_{\text{in}} = I_{\text{av}} * \Delta t * 3600$

Step 6. A proper value is assumed for the outflow value, $Q(H_r)_{\text{assumed}}$.

Step 7. H_r corresponding to this $Q(H_r)_{\text{assumed}}$ is calculated by the relation of $Q(H_r)$.

Step 8. Average of the two successive outflows (Q_{av}) is computed for $Q(H_r)_{\text{assumed}}$.

Step 9. Volume of water leaving the conduit is computed by $V_{\text{out}} = Q_{\text{av}} * \Delta t * 3600$

Step 10: The accumulated volume of water is computed from $V_{acc} = V_{in} - V_{out}$

Step 11: $V_r =$ Reservoir volume at $t_0 + V_{acc}$

Step 12. Volume of water in the reservoir (V_i) is calculated according to the integral of the area-elevation relation $A(H_r)$.

$$V_i = \frac{a}{4} H_r^4 - \frac{b}{3} H_r^3 + \frac{c}{2} H_r^2 \quad (3.10)$$

Step 14. Iteration is carried out between V_r and V_i by changing the assumed Q value ($Q(H_r)_{assumed}$).

Iteration is continued until both calculated volume values converge. Finally, the outflow discharge, Q value is found as a result of the successive application of these steps and the inflow and outflow hydrographs are plotted.

3.5 Outputs of the Software

The software has been developed to create water surface profiles for the different flow conditions mentioned before. The outputs from the software are as follows:

- Water surface profile
- Conduit Summary Table
- Water Surface Profile Table
- Routing Table
- Inflow-Outflow Hydrograph

The designer who will work with the program can monitor the invent behavior for different flow situations and adjust the required culvert dimensions for the given discharge. All flow states coded in the scope of this study are illustrated with numerical examples in the next chapter.

CHAPTER 4

APPLICATION OF THE SOFTWARE

4.1 Introduction

In the application of this study, various flow conditions are considered to obtain the corresponding water surface profiles. Different flow and conduit (culvert or tunnel) parameters are used to observe their effectiveness. Inlet and outlet control conditions will be performed by changing the characteristics of the conduit. The overall analysis is outlined in the Figure 4.1.

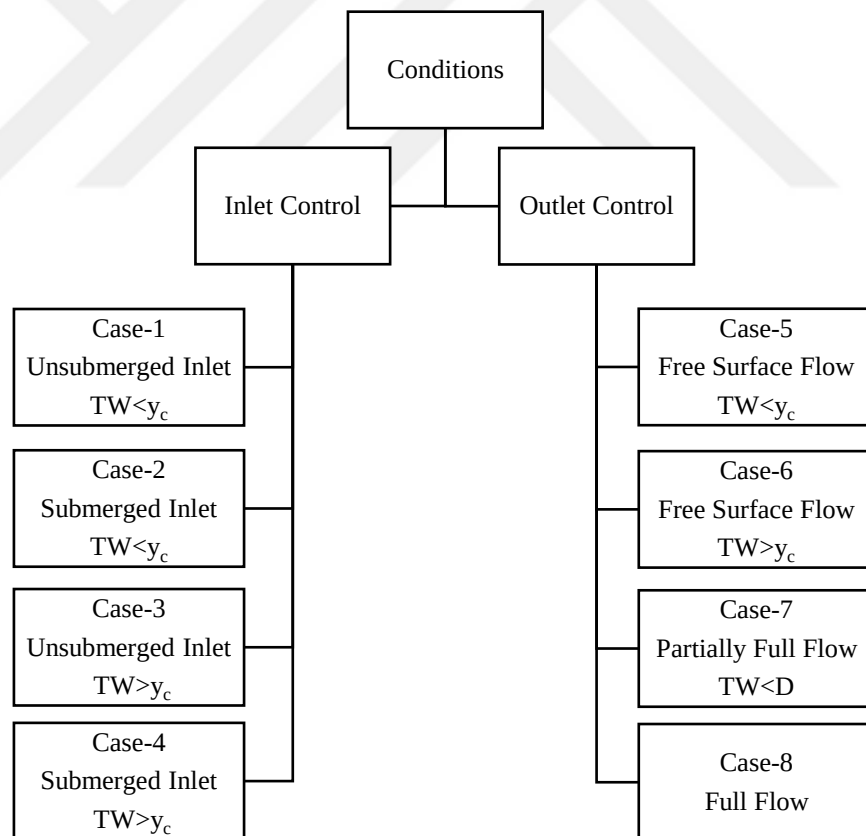


Figure 4.1 Flow conditions considered in analyses

4.2 Data Selection for Cases

All possible flow conditions valid for inlet and outlet control cases are analyzed. For each control, four conditions are valid and a total of eight analyses are performed for a single section type. For both two section types for culvert (circular and rectangular), and circular section for tunnel, a total of twenty-four cases are applied. Input data for all cases are shown in the following tables in which, Q_d is the design discharge, D is the diameter, B is the bottom width, H is the conduit height, S_o is the conduit slope, L is the conduit length, TW is the tailwater depth and n is the Manning's roughness coefficient. In the following analyses the n -values have been taken from FHWA.

The data used in this application are arbitrary, random values to observe different flow conditions. To make the comparison between two cases only the related value is changed, and the same data are used for the other parameters.

Table 4.1 Input data for inlet control, concrete circular culvert

Input Data	Case 1	Case 2	Case 3	Case 4
Section Type	Circular	Circular	Circular	Circular
Inlet Types	Square Edge with Headwall	Square Edge with Headwall	Square Edge with Headwall	Square Edge with Headwall
Q_d (m ³ /s)	3	5	3	3.5
D (m)	1.5	1.5	1.5	1.5
S_o	0.02	0.02	0.02	0.02
n	0.01	0.01	0.01	0.01
L (m)	40	40	40	40
TW (m)	0.4	0.4	1.7	1.7
Outlet Elevation (m)	0	0	0	0
Roadway Crest Length (m)	10	10	10	10
Roadway Crest Elevation (m)	4	4	4	4

Table 4.2 Input data for outlet control, concrete circular culvert

Input Data	Case 5	Case 6	Case 7	Case 8
Section Type	Circular	Circular	Circular	Circular
Inlet Types	Square Edge with Headwall	Square Edge with Headwall	Square Edge with Headwall	Square Edge with Headwall
Q_d (m ³ /s)	3	3	6.5	6.5
D (m)	1.5	1.5	1.5	1.5
S_o	0.001	0.001	0.001	0.001
n	0.01	0.01	0.01	0.01
L (m)	40	40	40	40
TW (m)	0.4	1	1	1.7
Outlet Elevation (m)	0	0	0	0
Roadway Crest Length (m)	10	10	10	10
Roadway Crest Elevation (m)	4	4	4	4

Table 4.3 Input data for inlet control, concrete rectangular box culvert

Input Data	Case 1	Case 2	Case 3	Case 4
Section Type	Rectangular	Rectangular	Rectangular	Rectangular
Inlet Types	30°-75° Wingwall Flares	30°-75° Wingwall Flares	30°-75° Wingwall Flares	30°-75° Wingwall Flares
Q_d (m ³ /s)	5	10	5	10
B (m)	2	2	2	2
H (m)	2	2	2	2
S_o	0.01	0.01	0.01	0.01
n	0.015	0.015	0.015	0.015
L (m)	75	75	75	75
TW (m)	0.5	0.5	1.2	2.1
Outlet Elevation (m)	0	0	0	0
Roadway Crest Length (m)	25	25	25	25
Roadway Crest Elevation (m)	5	5	5	5

Table 4.4 Input data for outlet control, concrete rectangular box culvert

Input Data	Case 5	Case 6	Case 7	Case 8
Section Type	Rectangular	Rectangular	Rectangular	Rectangular
Inlet Types	30°-75° Wingwall Flares	30°-75° Wingwall Flares	30°-75° Wingwall Flares	30°-75° Wingwall Flares
Q_d (m ³ /s)	5	5	13	13
B (m)	2	2	2	2
H (m)	2	2	2	2
S_o	0.003	0.003	0.003	0.003
n	0.015	0.015	0.015	0.015
L (m)	75	75	75	75
TW (m)	0.5	1.2	1.2	2.1
Outlet Elevation (m)	0	0	0	0
Roadway Crest Length (m)	25	25	25	25
Roadway Crest Elevation (m)	5	5	5	5

Table 4.5 Input data for inlet control, circular diversion tunnel

Input Data	Case 1	Case 2	Case 3	Case 4
Section Type	Circular	Circular	Circular	Circular
Inlet Types	Groove End with Headwall	Groove End with Headwall	Groove End with Headwall	Groove End with Headwall
Q_d (m ³ /s)	30	100	30	100
D (m)	5	5	5	5
S_o	0.015	0.015	0.015	0.015
n	0.011	0.011	0.011	0.011
L (m)	2000	2000	2000	2000
TW (m)	1	1	10	10
Outlet Elevation (m)	0	0	0	0
K_b	0.22	0.22	0.22	0.22
Roadway Crest Length (m)	2000	2000	2000	2000
Roadway Crest Elevation (m)	45	45	45	45

Table 4.6 Input data for outlet control, circular diversion tunnel

Input Data	Case 5	Case 6	Case 7	Case 8
Section Type	Circular	Circular	Circular	Circular
Inlet Types	Groove End with Headwall	Groove End with Headwall	Groove End with Headwall	Groove End with Headwall
Q_d (m ³ /s)	30	30	100	100
D (m)	5	5	5	5
S_o	0.001	0.001	0.001	0.001
n	0.011	0.011	0.011	0.011
L (m)	2000	2000	2000	2000
TW (m)	1	3	3	6
Outlet Elevation (m)	0	0	0	0
K_b	0.22	0.22	0.22	0.22
Roadway Crest Length (m)	2000	2000	2000	2000
Roadway Crest Elevation (m)	20	20	20	20

4.3 Software Output for Cases

4.3.1 Case-1

Case-1 is one of the basic conditions of inlet control with unsubmerged inlet and unsubmerged outlet. With the given flow data in the tables from Table 4.1 to 4.6, the water surface profiles through circular culvert, rectangular culvert and diversion tunnel can be examined.

The flow starts from the critical depth and reaches to normal depth if the conduit is long enough. The outlet end flows freely since the tailwater depth is lower than the critical depth. This circumstance causes a rapid change at the end of the structure to become equal to the tailwater depth. The flow profile through the conduit is shown in Figures 4.2 through 4.4 in which the flow profile S_2 is presented on the figure. The results of the analyses are outlined together with the results of HY-8 in Tables 4.7 through 4.12 in which y_o is the outlet depth, u_o is the outlet velocity, L_f is the

full flow length, L_{fr} is the free flow length in the culvert, and S_f is the friction slope. The results of the C-PAS are relatively in good agreement with those of HY-8.



Figure 4.2 Case-1 Circular section, water surface profile

Table 4.7 Case-1 Circular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	3.00	2.15	INLET	0.49	0.90	0.57	0.40	4.86	0.00	40.00
HY-8	3	2.16	INLET	0.49	0.90	0.57	0.40	4.84	0.00	40.00

Table 4.8 Case-1 Circular section, water surface profile output

$\Sigma\Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	0.90	1.11	2.71	0.42	0.010	0.0024
0.01	0.89	1.09	2.74	0.41	0.010	0.0024
0.04	0.88	1.08	2.78	0.41	0.010	0.0025
0.10	0.87	1.06	2.82	0.41	0.010	0.0026
0.18	0.86	1.05	2.86	0.41	0.010	0.0027
0.30	0.85	1.03	2.90	0.40	0.010	0.0028
0.45	0.84	1.02	2.94	0.40	0.010	0.0029
0.64	0.83	1.00	2.99	0.40	0.010	0.0030
0.86	0.82	0.99	3.03	0.40	0.010	0.0032
1.13	0.81	0.98	3.08	0.39	0.010	0.0033
1.44	0.80	0.96	3.12	0.39	0.010	0.0034
1.80	0.79	0.95	3.17	0.39	0.010	0.0036
2.20	0.78	0.93	3.23	0.38	0.010	0.0037
2.67	0.77	0.92	3.28	0.38	0.010	0.0039
3.19	0.76	0.90	3.33	0.38	0.010	0.0041
3.78	0.75	0.89	3.39	0.38	0.010	0.0042
4.44	0.74	0.87	3.45	0.37	0.010	0.0044
5.18	0.73	0.86	3.51	0.37	0.010	0.0047
6.01	0.72	0.84	3.57	0.37	0.010	0.0049
6.93	0.71	0.83	3.64	0.36	0.010	0.0051
7.96	0.70	0.81	3.70	0.36	0.010	0.0054
9.10	0.69	0.80	3.77	0.36	0.010	0.0057
10.37	0.68	0.78	3.84	0.35	0.010	0.0060
11.79	0.67	0.77	3.92	0.35	0.010	0.0063
13.37	0.66	0.75	4.00	0.34	0.010	0.0066
15.13	0.65	0.74	4.08	0.34	0.010	0.0070
17.11	0.64	0.72	4.16	0.34	0.010	0.0074
19.32	0.63	0.71	4.25	0.33	0.010	0.0078
21.82	0.62	0.69	4.34	0.33	0.010	0.0083
24.64	0.61	0.68	4.44	0.33	0.010	0.0088
27.85	0.60	0.66	4.53	0.32	0.010	0.0093
31.52	0.59	0.65	4.64	0.32	0.010	0.0099
35.75	0.58	0.63	4.74	0.31	0.010	0.0106
40.00	0.57	0.62	4.86	0.31	0.010	0.0113

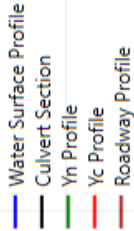
Routing

Figure 4.3 Case-1 Rectangular section, water surface profile

Table 4.9 Case-1 Rectangular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	5.00	2.11	INLET	0.68	0.86	0.68	0.50	3.65	0.00	75.00
HY-8	5.00	2.07	INLET	0.68	0.86	0.69	0.50	3.62	0.00	75.00

Table 4.10 Case-1 Rectangular section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	0.86	1.72	2.91	0.46	0.015	0.0053
0.04	0.85	1.70	2.94	0.46	0.015	0.0055
0.16	0.84	1.68	2.97	0.46	0.015	0.0057
0.38	0.83	1.66	3.01	0.45	0.015	0.0058
0.71	0.82	1.64	3.05	0.45	0.015	0.0060
1.16	0.81	1.62	3.08	0.45	0.015	0.0063
1.76	0.80	1.60	3.12	0.44	0.015	0.0065
2.54	0.79	1.58	3.16	0.44	0.015	0.0067
3.53	0.78	1.56	3.20	0.44	0.015	0.0069
4.78	0.77	1.54	3.24	0.44	0.015	0.0072
6.34	0.76	1.52	3.29	0.43	0.015	0.0074
8.32	0.75	1.50	3.33	0.43	0.015	0.0077
10.85	0.74	1.48	3.38	0.43	0.015	0.0080
14.13	0.73	1.46	3.42	0.42	0.015	0.0083
18.55	0.72	1.44	3.47	0.42	0.015	0.0086
24.81	0.71	1.42	3.52	0.42	0.015	0.0090
34.63	0.70	1.40	3.57	0.41	0.015	0.0094
54.15	0.69	1.38	3.62	0.41	0.015	0.0097
75.00	0.68	1.37	3.65	0.41	0.015	0.0100

MainWindow

Discharge and Culvert Data

Section Type:

Circular

Diameter(m)

5

Inlet Type:

Groove End Wt

Span(m)

2

Design Discharge(m³/s)

30

Rise(m)

2

Manning's Roughness Coef.

0.011

Slope(m/m)

0.015

Culvert Length(m)

2000

Site Data

Outlet Elv.(m)

0

Tailwater Depth(m)

1

Roadway Data

Crest Length(m)

2000

Crest Elv.(m)

45

Diversion Tunnel

Bending

☒

Radius of Bend

2

Angle of Bend

45

Water Surface Profile

Tables

Routing

The graph displays the water surface profile for a tunnel section. The x-axis represents distance in meters (0 to 2000), and the y-axis represents elevation in meters (0 to 50). The profiles shown are:

- Water Surface Profile (Blue line):** Starts at approximately 32m elevation at x=0 and rises to about 45m at x=2000.
- Tunnel Section (Black line):** A horizontal line at approximately 30m elevation.
- Yn Profile (Green line):** Starts at approximately 30m elevation at x=0 and rises to about 45m at x=2000.
- Yc Profile (Red line):** Starts at approximately 30m elevation at x=0 and rises to about 45m at x=2000.

A label S_2 is placed near the start of the profiles at x=0.

Figure 4.4 Case-1 Tunnel section, water surface profile

54

Table 4.11 Case-1 Tunnel section, summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	30.00	32.87	INLET	1.16	2.07	1.16	1.00	8.68	0.00	2000.00
HY-8	30.00	32.85	INLET	1.16	2.07	1.16	1.00	8.67	0.00	2000.00

Table 4.12 Case-1 Tunnel section, water surface profile output

$\Sigma\Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	2.07	7.67	3.91	1.10	0.011	0.0016
0.01	2.06	7.62	3.93	1.09	0.011	0.0017
0.03	2.05	7.58	3.96	1.09	0.011	0.0017
0.06	2.04	7.53	3.99	1.09	0.011	0.0017
0.11	2.03	7.48	4.01	1.08	0.011	0.0018
0.18	2.02	7.43	4.04	1.08	0.011	0.0018
0.26	2.01	7.38	4.07	1.07	0.011	0.0018
0.36	2.00	7.33	4.09	1.07	0.011	0.0019
0.48	1.99	7.28	4.12	1.07	0.011	0.0019
0.61	1.98	7.23	4.15	1.06	0.011	0.0019
0.76	1.97	7.18	4.18	1.06	0.011	0.0020
0.93	1.96	7.13	4.20	1.05	0.011	0.0020
1.12	1.95	7.09	4.23	1.05	0.011	0.0020
1.33	1.94	7.04	4.26	1.05	0.011	0.0021
1.56	1.93	6.99	4.29	1.04	0.011	0.0021
1.81	1.92	6.94	4.32	1.04	0.011	0.0022
2.08	1.91	6.89	4.35	1.03	0.011	0.0022
2.38	1.90	6.84	4.38	1.03	0.011	0.0022
2.69	1.89	6.79	4.42	1.03	0.011	0.0023
3.03	1.88	6.75	4.45	1.02	0.011	0.0023
3.40	1.87	6.70	4.48	1.02	0.011	0.0024
3.79	1.86	6.65	4.51	1.01	0.011	0.0024
4.21	1.85	6.60	4.55	1.01	0.011	0.0025
4.65	1.84	6.55	4.58	1.01	0.011	0.0025
.	.	.	.	.	.	.
295.27	1.21	3.66	8.19	0.71	0.011	0.0128
330.41	1.20	3.62	8.29	0.71	0.011	0.0132
376.93	1.19	3.58	8.39	0.70	0.011	0.0136
444.71	1.18	3.53	8.49	0.70	0.011	0.0141
566.35	1.17	3.49	8.59	0.69	0.011	0.0146
641.56	1.16	3.46	8.68	0.69	0.011	0.0150
2000.00	1.16	3.46	8.68	0.69	0.011	0.0150

4.3.2 Case-2

Case-2 is the condition which includes the submerged upstream section and the unsubmerged downstream section with inlet control. This condition may be caused by insufficient dimensions of the conduit. To obtain this condition, only the flow discharge is increased, and all the remaining data are the same as the Case-1.

The flow starts with the critical depth and reaches to normal depth if the culvert is long enough. Since the outlet flows freely, a rapid depth change occurs at the end of the structure to become equal to the tailwater depth.

The flow profile through the conduit is shown in Figures 4.5 through 4.7 in which the flow profiles, such as S_2 are presented on the figure. The results of the analyses are outlined in Tables 4.13 through 4.18. The results of the C-PAS are relatively in good agreement with those of HY-8.



Figure 4.5 Case-2 Circular section, water surface profile

Table 4.13 Case-2 Circular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	5.00	2.84	INLET	0.65	1.17	0.78	0.40	5.43	0.00	40.00
HY-8	5.00	2.83	INLET	0.64	1.16	0.78	0.40	5.37	0.00	40.00

Table 4.14 Case-2 Circular section, water surface profile output

$\Sigma \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	1.17	1.47	3.39	0.46	0.010	0.0033
0.01	1.16	1.46	3.42	0.45	0.010	0.0034
0.04	1.15	1.45	3.45	0.45	0.010	0.0034
0.09	1.14	1.43	3.48	0.45	0.010	0.0035
0.17	1.13	1.42	3.52	0.45	0.010	0.0036
0.28	1.12	1.41	3.55	0.45	0.010	0.0036
0.41	1.11	1.40	3.58	0.45	0.010	0.0037
0.57	1.10	1.38	3.62	0.45	0.010	0.0038
0.76	1.09	1.37	3.65	0.45	0.010	0.0039
0.98	1.08	1.36	3.69	0.45	0.010	0.0040
1.24	1.07	1.34	3.73	0.45	0.010	0.0041
1.53	1.06	1.33	3.76	0.45	0.010	0.0042
1.86	1.05	1.31	3.80	0.44	0.010	0.0043
2.23	1.04	1.30	3.84	0.44	0.010	0.0044
2.64	1.03	1.29	3.89	0.44	0.010	0.0045
3.09	1.02	1.27	3.93	0.44	0.010	0.0046
3.59	1.01	1.26	3.97	0.44	0.010	0.0047
4.14	1.00	1.24	4.02	0.44	0.010	0.0049
4.75	0.99	1.23	4.06	0.43	0.010	0.0050
5.41	0.98	1.22	4.11	0.43	0.010	0.0052
6.13	0.97	1.20	4.16	0.43	0.010	0.0053
6.92	0.96	1.19	4.21	0.43	0.010	0.0055
7.78	0.95	1.17	4.26	0.43	0.010	0.0057
8.72	0.94	1.16	4.32	0.42	0.010	0.0058
.	.	.	.	.	.	.
24.02	0.84	1.01	4.94	0.40	0.010	0.0083
26.41	0.83	1.00	5.02	0.40	0.010	0.0086
29.03	0.82	0.98	5.10	0.39	0.010	0.0090
31.92	0.81	0.97	5.17	0.39	0.010	0.0093
35.10	0.80	0.95	5.26	0.39	0.010	0.0097
38.62	0.79	0.94	5.34	0.39	0.010	0.0101
40.00	0.78	0.92	5.43	0.38	0.010	0.0106



Figure 4.6 Case-2 Rectangular section, water surface profile

Table 4.15 Case-2 Rectangular section, culvert summary table

Software	Q	HW	Flow Type	y_n	y_c	y_o	TW	u_o	L_f	L_{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	10.00	2.96	INLET	1.14	1.37	1.15	0.50	4.36	0.00	75.00
HY-8	10.00	2.89	INLET	1.14	1.37	1.15	0.50	4.35	0.00	75.00

Table 4.16 Case-2 Rectangular section, water surface profile output

$\Sigma \Delta x$	y	A	u	R	n	S_f
m	m	m ²	m/s	m		m/m
0.00	1.37	2.73	3.66	0.58	0.015	0.0063
0.03	1.36	2.71	3.69	0.58	0.015	0.0064
0.13	1.35	2.69	3.71	0.57	0.015	0.0065
0.29	1.34	2.67	3.74	0.57	0.015	0.0066
0.54	1.33	2.65	3.77	0.57	0.015	0.0068
0.87	1.32	2.63	3.80	0.57	0.015	0.0069
1.31	1.31	2.61	3.83	0.57	0.015	0.0070
1.85	1.30	2.59	3.86	0.56	0.015	0.0072
2.52	1.29	2.57	3.89	0.56	0.015	0.0073
3.34	1.28	2.55	3.92	0.56	0.015	0.0075
4.33	1.27	2.53	3.95	0.56	0.015	0.0076
5.51	1.26	2.51	3.98	0.56	0.015	0.0078
6.93	1.25	2.49	4.01	0.55	0.015	0.0079
8.62	1.24	2.47	4.05	0.55	0.015	0.0081
10.67	1.23	2.45	4.08	0.55	0.015	0.0083
13.14	1.22	2.43	4.11	0.55	0.015	0.0085
16.16	1.21	2.41	4.15	0.55	0.015	0.0087
19.93	1.20	2.39	4.18	0.54	0.015	0.0088
24.74	1.19	2.37	4.22	0.54	0.015	0.0090
31.10	1.18	2.35	4.25	0.54	0.015	0.0092
40.08	1.17	2.33	4.29	0.54	0.015	0.0094
54.29	1.16	2.31	4.33	0.54	0.015	0.0097
75.00	1.15	2.29	4.36	0.53	0.015	0.0099

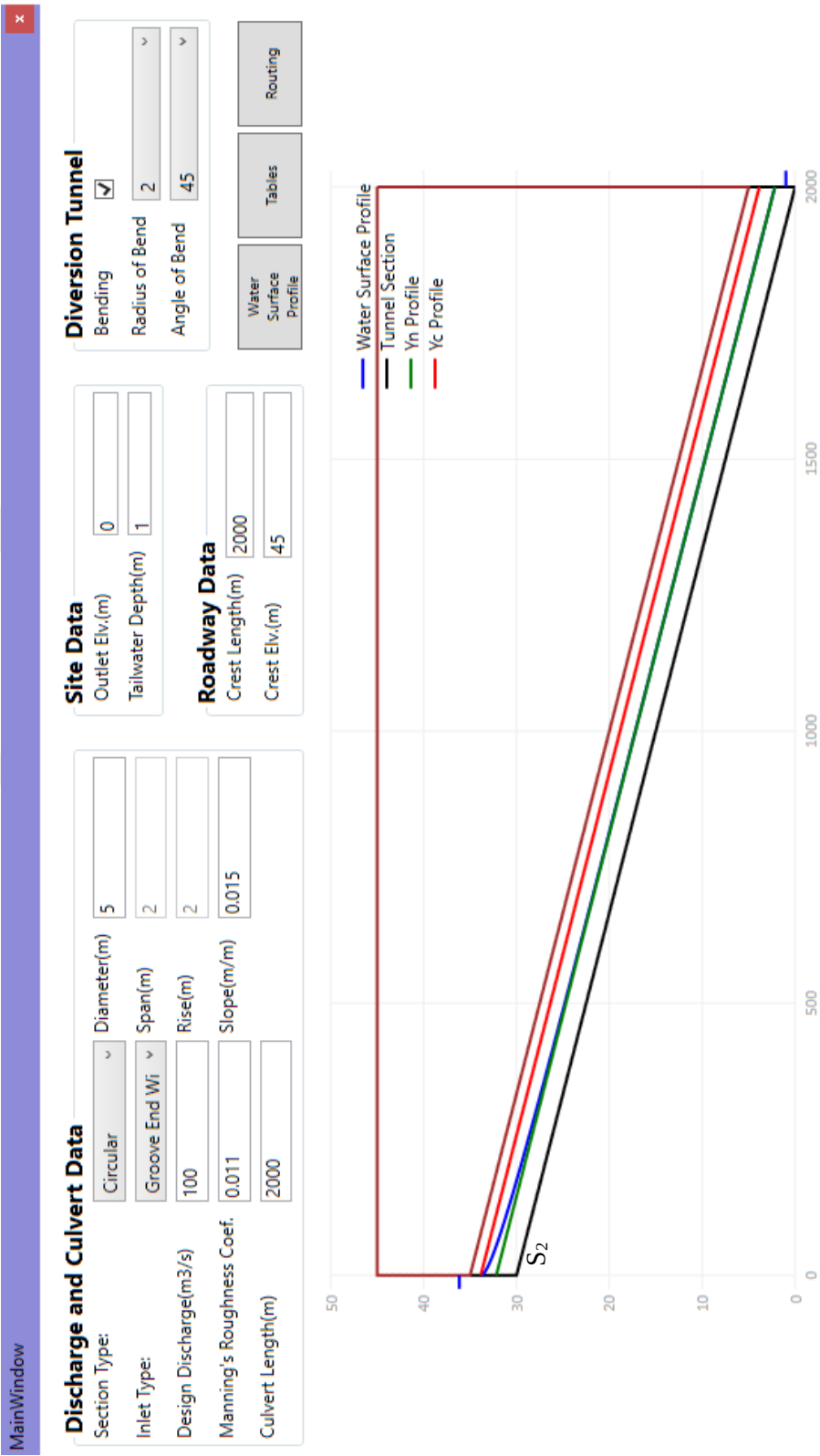


Figure 4.7 Case-2 Tunnel section, water surface profile

Table 4.17 Case-2 Tunnel section, summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	100.00	36.15	INLET	2.18	3.85	2.18	1.00	12.15	0.00	2000.00
HY-8	100.00	36.06	INLET	2.18	3.85	2.18	1.00	12.14	0.00	2000.00

Table 4.18 Case-2 Tunnel section, water surface profile output

ΣΔx	y	A	u	R	n	Sf
m	m	m ²	m/s	m		m/m
0.00	3.85	16.24	6.16	1.52	0.011	0.0026
0.00	3.84	16.20	6.17	1.51	0.011	0.0026
0.02	3.83	16.16	6.19	1.51	0.011	0.0027
0.04	3.82	16.11	6.21	1.51	0.011	0.0027
0.07	3.81	16.07	6.22	1.51	0.011	0.0027
0.11	3.80	16.03	6.24	1.51	0.011	0.0027
0.16	3.79	15.99	6.26	1.51	0.011	0.0027
0.22	3.78	15.94	6.27	1.51	0.011	0.0027
0.29	3.77	15.90	6.29	1.51	0.011	0.0028
0.37	3.76	15.86	6.31	1.51	0.011	0.0028
0.46	3.75	15.81	6.32	1.51	0.011	0.0028
0.56	3.74	15.77	6.34	1.51	0.011	0.0028
0.67	3.73	15.73	6.36	1.51	0.011	0.0028
0.79	3.72	15.68	6.38	1.51	0.011	0.0028
0.92	3.71	15.64	6.39	1.51	0.011	0.0029
1.06	3.70	15.60	6.41	1.50	0.011	0.0029
1.21	3.69	15.55	6.43	1.50	0.011	0.0029
1.37	3.68	15.51	6.45	1.50	0.011	0.0029
.	.	.	.	.	.	.
621.29	2.26	8.64	11.57	1.17	0.011	0.0131
660.69	2.25	8.59	11.64	1.17	0.011	0.0133
706.29	2.24	8.54	11.71	1.16	0.011	0.0136
760.21	2.23	8.49	11.78	1.16	0.011	0.0138
825.93	2.22	8.44	11.85	1.16	0.011	0.0140
909.66	2.21	8.39	11.92	1.15	0.011	0.0142
1024.25	2.20	8.34	11.99	1.15	0.011	0.0144
1203.95	2.19	8.29	12.06	1.15	0.011	0.0147
1611.06	2.18	8.24	12.13	1.14	0.011	0.0149
2000.00	2.18	8.23	12.15	1.14	0.011	0.0150

4.3.3 Case-3

Case-3 represents the condition that the inlet edge is unsubmerged, and the outlet end is submerged for inlet control. This condition may be caused by an obstruction placed on the downstream of the culvert. The obstruction may increase the backwater beyond the culvert invert top elevation and affect the downstream conditions if the length between the obstruction and the culvert is not sufficiently long.

Greater tailwater depth than the critical depth causes a hydraulic jump to occur inside the culvert. The flow starts with the critical depth just downstream of the culvert entrance and proceeds until its sequent depth becomes equal to the downstream flow profile depth. Also, downstream flow profile starts with the tailwater depth and proceeds to upstream until its sequent depth become equals to upstream flow profile. Two gradually varied profiles are formed inside the culvert, upstream and downstream. At the intersection point, hydraulic jump occurs with the defined length given before.

The flow profile through the conduit is shown in Figures 4.8 through 4.10 in which the flow profiles are presented on the figure. The results of the analyses are outlined in Tables 4.19 through 4.24. The results of the C-PAS are relatively in good agreement with those of HY-8.

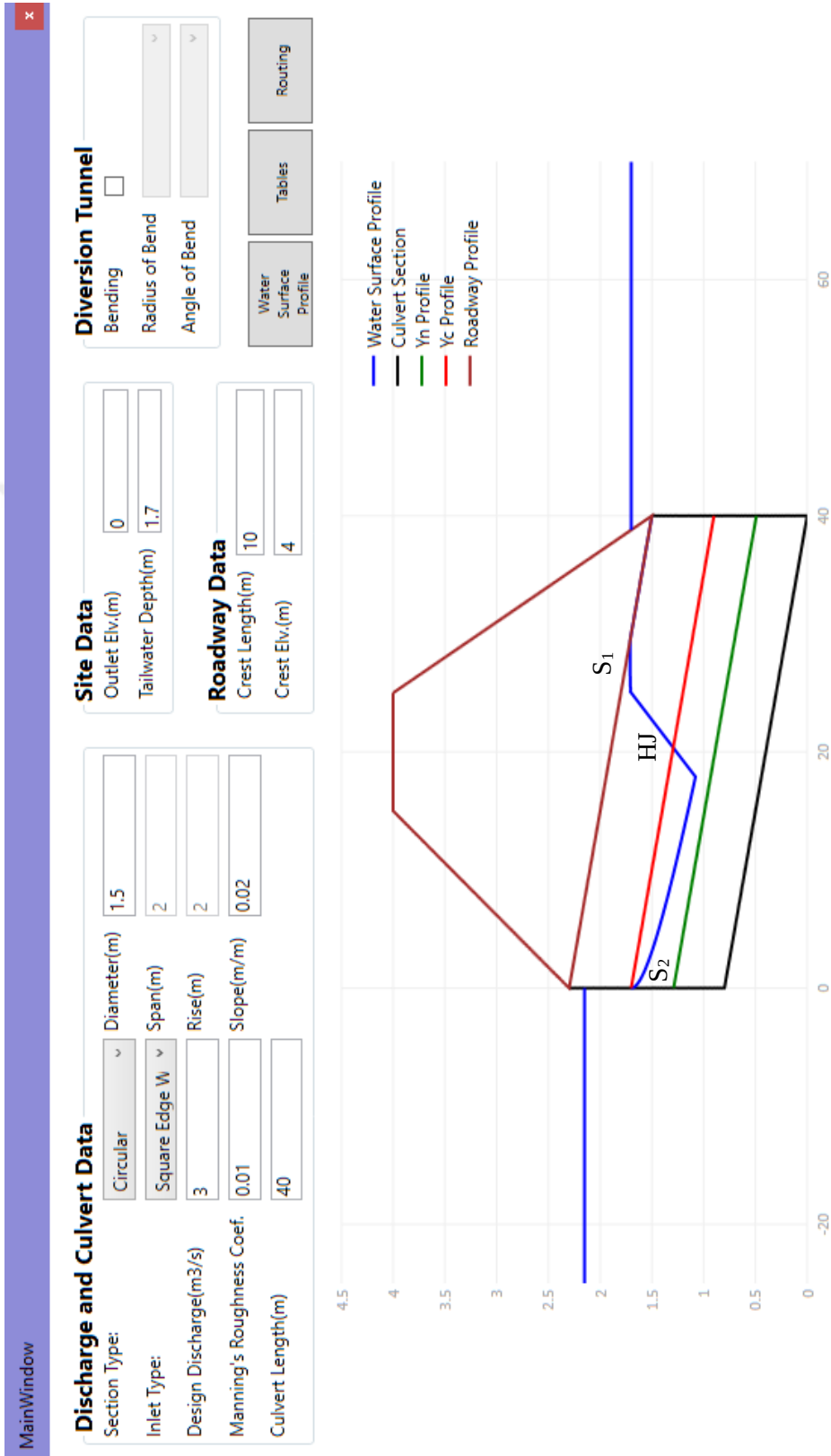


Table 4.19 Case-3 Circular section, culvert summary table

Software	Q	HW	Flow Type	y_n	y_c	y_o	TW	u_o	L_f	L_{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	3.00	2.15	INLET	0.49	0.90	1.50	1.70	1.70	10.56	29.44
HY-8	3.00	2.16	INLET	0.49	0.90	1.50	1.70	1.70	10.56	29.44

Table 4.20 Case-3 Circular section, water surface profile output

$\Sigma\Delta x$	y	A	u	R	n	S_f
m	m	m ²	m/s	m		m/m
0.00	0.90	1.11	2.71	0.42	0.010	0.0024
0.01	0.89	1.09	2.74	0.41	0.010	0.0024
0.04	0.88	1.08	2.78	0.41	0.010	0.0025
0.10	0.87	1.06	2.82	0.41	0.010	0.0026
0.18	0.86	1.05	2.86	0.41	0.010	0.0027
0.30	0.85	1.03	2.90	0.40	0.010	0.0028
0.45	0.84	1.02	2.94	0.40	0.010	0.0029
0.64	0.83	1.00	2.99	0.40	0.010	0.0030
0.86	0.82	0.99	3.03	0.40	0.010	0.0032
.	.	.	.	.	.	.
6.01	0.72	0.84	3.57	0.37	0.010	0.0049
6.93	0.71	0.83	3.64	0.36	0.010	0.0051
7.96	0.70	0.81	3.70	0.36	0.010	0.0054
9.10	0.69	0.80	3.77	0.36	0.010	0.0057
10.37	0.68	0.78	3.84	0.35	0.010	0.0060
11.79	0.67	0.77	3.92	0.35	0.010	0.0063
13.37	0.66	0.75	4.00	0.34	0.010	0.0066
15.13	0.65	0.74	4.08	0.34	0.010	0.0070
17.11	0.64	0.72	4.16	0.34	0.010	0.0074
17.89	0.64	0.72	4.19	0.34	0.010	0.0075
25.09	1.41	1.72	1.74	0.43	0.010	0.0009
25.33	1.41	1.72	1.74	0.43	0.010	0.0009
25.55	1.42	1.73	1.73	0.43	0.010	0.0009
26.02	1.43	1.74	1.73	0.43	0.010	0.0009
26.49	1.44	1.74	1.72	0.42	0.010	0.0009
26.96	1.45	1.75	1.72	0.42	0.010	0.0009
27.44	1.46	1.75	1.71	0.42	0.010	0.0009
27.92	1.47	1.76	1.71	0.41	0.010	0.0010
28.42	1.48	1.76	1.70	0.40	0.010	0.0010
28.92	1.49	1.77	1.70	0.40	0.010	0.0010
29.44	1.50	1.77	1.70	0.38	0.010	0.0011
40.00	1.50	1.77	1.70	0.38	0.010	0.0011

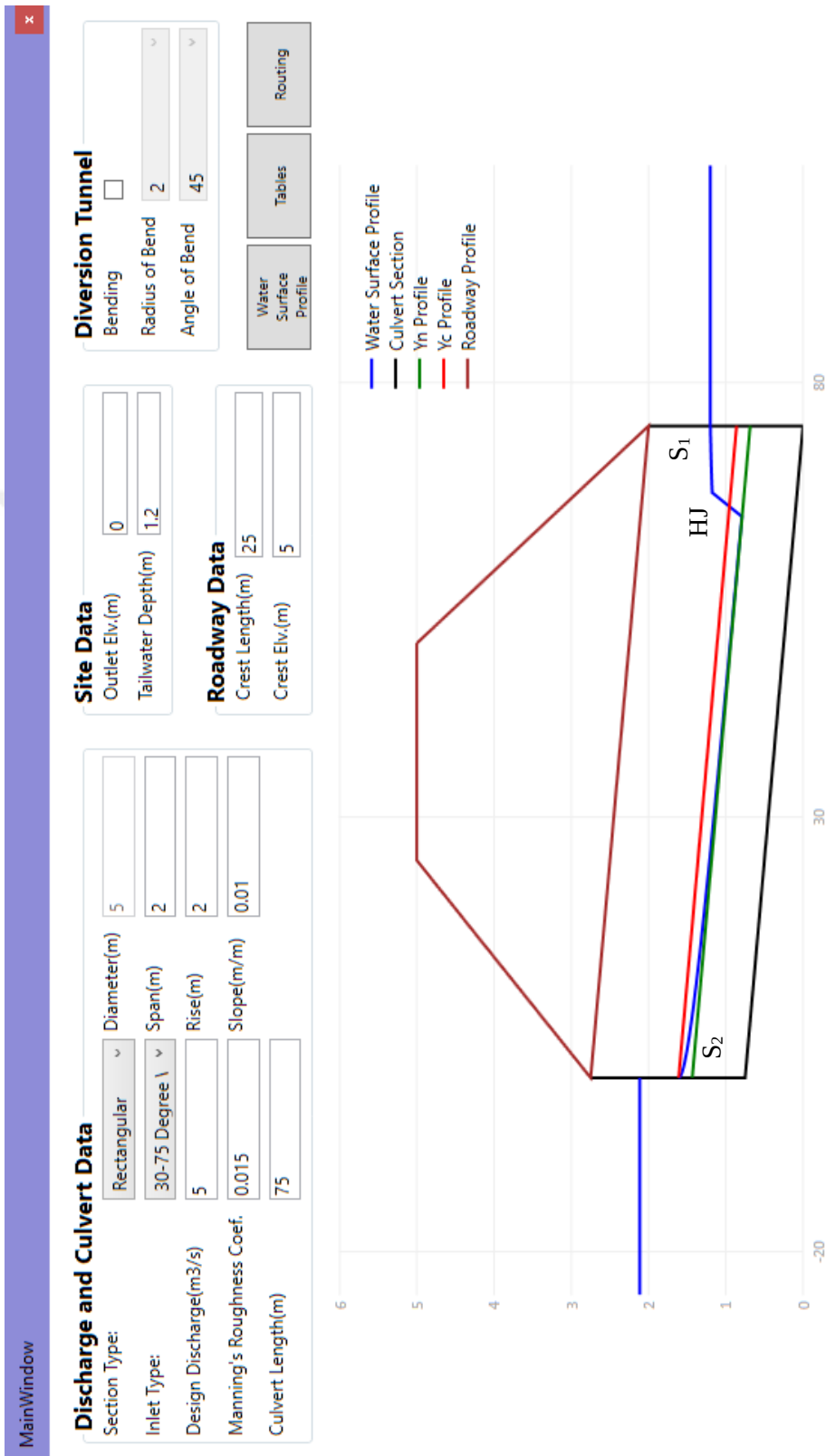


Figure 4.9 Case-3 Rectangular section, water surface profile

Table 4.21 Case-3 Rectangular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	5.00	2.11	INLET	0.68	0.86	1.20	1.20	2.08	0.00	75.00
HY-8	5.00	2.07	INLET	0.68	0.86	1.20	1.20	2.08	0.00	75.00

Table 4.22 Case-3 Rectangular section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	0.86	1.72	2.91	0.46	0.015	0.0053
0.04	0.85	1.70	2.94	0.46	0.015	0.0055
0.16	0.84	1.68	2.97	0.46	0.015	0.0057
0.38	0.83	1.66	3.01	0.45	0.015	0.0058
0.71	0.82	1.64	3.05	0.45	0.015	0.0060
1.16	0.81	1.62	3.08	0.45	0.015	0.0063
1.76	0.80	1.60	3.12	0.44	0.015	0.0065
2.54	0.79	1.58	3.16	0.44	0.015	0.0067
3.53	0.78	1.56	3.20	0.44	0.015	0.0069
4.78	0.77	1.54	3.24	0.44	0.015	0.0072
6.34	0.76	1.52	3.29	0.43	0.015	0.0074
8.32	0.75	1.50	3.33	0.43	0.015	0.0077
10.85	0.74	1.48	3.38	0.43	0.015	0.0080
14.13	0.73	1.46	3.42	0.42	0.015	0.0083
18.55	0.72	1.44	3.47	0.42	0.015	0.0086
24.81	0.71	1.42	3.52	0.42	0.015	0.0090
34.63	0.70	1.40	3.57	0.41	0.015	0.0094
54.15	0.69	1.38	3.62	0.41	0.015	0.0097
64.57	0.69	1.38	3.64	0.41	0.015	0.0098
67.32	1.10	2.20	2.27	0.52	0.015	0.0028
68.05	1.11	2.22	2.25	0.53	0.015	0.0027
68.78	1.12	2.24	2.23	0.53	0.015	0.0026
69.53	1.13	2.26	2.21	0.53	0.015	0.0026
70.29	1.14	2.28	2.19	0.53	0.015	0.0025
71.05	1.15	2.30	2.17	0.53	0.015	0.0024
71.82	1.16	2.32	2.16	0.54	0.015	0.0024
72.61	1.17	2.34	2.14	0.54	0.015	0.0023
73.40	1.18	2.36	2.12	0.54	0.015	0.0023
74.20	1.19	2.38	2.10	0.54	0.015	0.0022
75.00	1.20	2.40	2.08	0.55	0.015	0.0022

MainWindow

Discharge and Culvert Data

Section Type:

Circular

Diameter(m)

5

Inlet Type:

Groove End Wi

Span(m)

2

Design Discharge(m³/s)

30

Rise(m)

2

Manning's Roughness Coef.

0.011

Slope(m/m)

0.015

Culvert Length(m)

2000

Site Data

Outlet Elv.(m)

0

Tailwater Depth(m)

10

Roadway Data

Crest Length(m)

2000

Crest Elv.(m)

40

Diversion Tunnel

Bending

☒

Radius of Bend

2

Angle of Bend

45

Water Surface Profile

Tables

Routing



Figure 4.10 Case-3 Tunnel section, water surface profile

Table 4.23 Case-3 Tunnel section, summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	30.00	32.87	INLET	1.16	2.07	5.00	10.00	1.53	338.06	1661.94
HY-8	30.00	32.85	INLET	1.16	2.07	5.00	10.00	1.53	338.06	1661.94

Table 4.24 Case-3 Tunnel section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	2.07	7.67	3.91	1.10	0.011	0.0016
0.01	2.06	7.62	3.93	1.09	0.011	0.0017
0.03	2.05	7.58	3.96	1.09	0.011	0.0017
0.06	2.04	7.53	3.99	1.09	0.011	0.0017
0.11	2.03	7.48	4.01	1.08	0.011	0.0018
0.18	2.02	7.43	4.04	1.08	0.011	0.0018
0.26	2.01	7.38	4.07	1.07	0.011	0.0018
0.36	2.00	7.33	4.09	1.07	0.011	0.0019
0.48	1.99	7.28	4.12	1.07	0.011	0.0019
0.61	1.98	7.23	4.15	1.06	0.011	0.0019
0.76	1.97	7.18	4.18	1.06	0.011	0.0020
0.93	1.96	7.13	4.20	1.05	0.011	0.0020
.	.	.	.	.	.	.
295.27	1.21	3.66	8.19	0.71	0.011	0.0128
330.41	1.20	3.62	8.29	0.71	0.011	0.0132
376.93	1.19	3.58	8.39	0.70	0.011	0.0136
444.71	1.18	3.53	8.49	0.70	0.011	0.0141
566.35	1.17	3.49	8.59	0.69	0.011	0.0146
1563.22	1.16	3.46	8.68	0.69	0.011	0.0150
1583.69	3.78	15.93	1.88	1.51	0.011	0.0002
1583.85	3.78	15.93	1.88	1.51	0.011	0.0002
1584.30	3.79	15.97	1.88	1.51	0.011	0.0002
1584.92	3.80	16.01	1.87	1.51	0.011	0.0002
1585.53	3.81	16.05	1.87	1.51	0.011	0.0002
1586.14	3.82	16.10	1.86	1.51	0.011	0.0002
1586.76	3.83	16.14	1.86	1.51	0.011	0.0002
1587.37	3.84	16.18	1.85	1.51	0.011	0.0002
1587.99	3.85	16.22	1.85	1.52	0.011	0.0002
1588.60	3.86	16.27	1.84	1.52	0.011	0.0002
.	.	.	.	.	.	.
1660.59	4.98	19.63	1.53	1.30	0.011	0.0002
1661.26	4.99	19.63	1.53	1.29	0.011	0.0002
2000.00	5.00	19.63	1.53	1.25	0.011	0.0002

4.3.4 Case-4

Case-4 simulates the inlet control condition that both ends are submerged. The flow starts with the critical depth and intersects with the sequent depth of the downstream profile. Hydraulic jump occurs in this intersection. The place of the hydraulic jump can be shifted by increasing or decreasing the discharge value.

The flow profile through the conduit is shown in Figures 4.11 through 4.13 in which the flow profiles are presented on the figure. The results of the analyses are outlined in Tables 4.25 through 4.30. The results of the C-PAS are relatively in good agreement with those of HY-8.

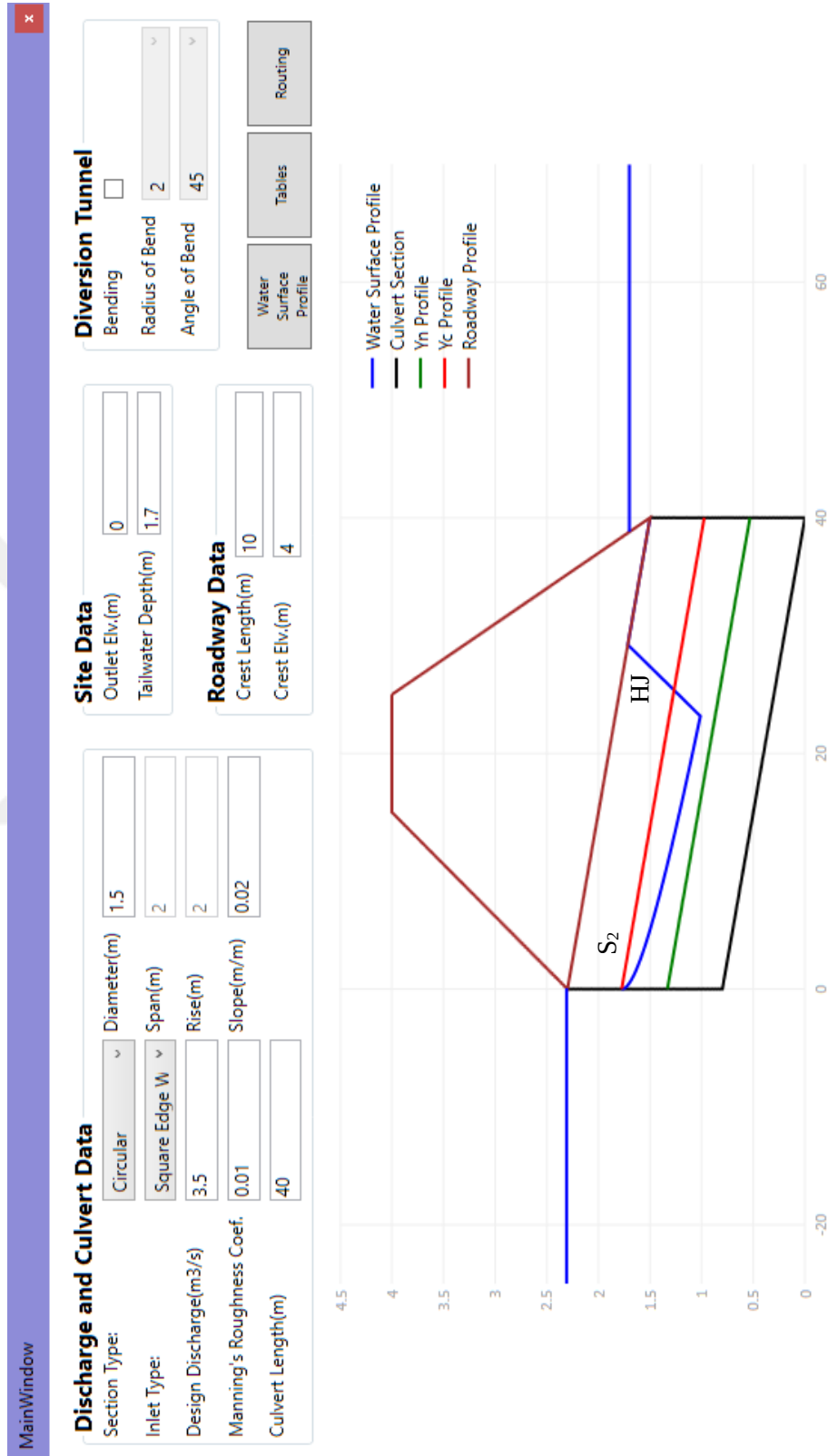


Figure 4.11 Case-4 Circular section, water surface profile

Table 4.25 Case-4 Circular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	3.50	2.31	INLET	0.53	0.98	1.50	1.70	1.98	10.78	29.22
HY-8	3.50	2.31	INLET	0.53	0.97	1.50	1.70	1.98	9.39	30.61

Table 4.26 Case-4 Circular section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	0.98	1.22	2.88	0.43	0.010	0.0025
0.01	0.97	1.20	2.91	0.43	0.010	0.0026
0.04	0.96	1.19	2.95	0.43	0.010	0.0027
0.09	0.95	1.17	2.98	0.43	0.010	0.0028
0.18	0.94	1.16	3.02	0.42	0.010	0.0029
0.29	0.93	1.14	3.06	0.42	0.010	0.0030
0.43	0.92	1.13	3.10	0.42	0.010	0.0031
0.60	0.91	1.12	3.14	0.42	0.010	0.0032
0.81	0.90	1.10	3.18	0.42	0.010	0.0033
1.06	0.89	1.09	3.22	0.41	0.010	0.0034
1.34	0.88	1.07	3.27	0.41	0.010	0.0035
1.67	0.87	1.06	3.31	0.41	0.010	0.0036
2.04	0.86	1.04	3.36	0.41	0.010	0.0038
2.46	0.85	1.03	3.41	0.40	0.010	0.0039
2.94	0.84	1.01	3.46	0.40	0.010	0.0041
3.47	0.83	1.00	3.51	0.40	0.010	0.0042
4.06	0.82	0.98	3.57	0.39	0.010	0.0044
4.71	0.81	0.97	3.62	0.39	0.010	0.0046
5.44	0.80	0.95	3.68	0.39	0.010	0.0048
6.25	0.79	0.94	3.74	0.39	0.010	0.0050
7.14	0.78	0.92	3.80	0.38	0.010	0.0052
8.13	0.77	0.91	3.86	0.38	0.010	0.0054
9.22	0.76	0.89	3.92	0.38	0.010	0.0057
10.42	0.75	0.88	3.99	0.37	0.010	0.0059
11.75	0.74	0.86	4.06	0.37	0.010	0.0062
13.22	0.73	0.85	4.13	0.37	0.010	0.0065
14.85	0.72	0.83	4.21	0.36	0.010	0.0068
16.65	0.71	0.82	4.29	0.36	0.010	0.0072
18.64	0.70	0.80	4.36	0.36	0.010	0.0075
20.86	0.69	0.79	4.45	0.35	0.010	0.0079
23.16	0.68	0.77	4.53	0.35	0.010	0.0083
29.22	1.50	1.77	1.98	0.38	0.010	0.0015
31.38	1.50	1.77	1.98	0.38	0.010	0.0015
40.00	1.50	1.77	1.98	0.38	0.010	0.0015

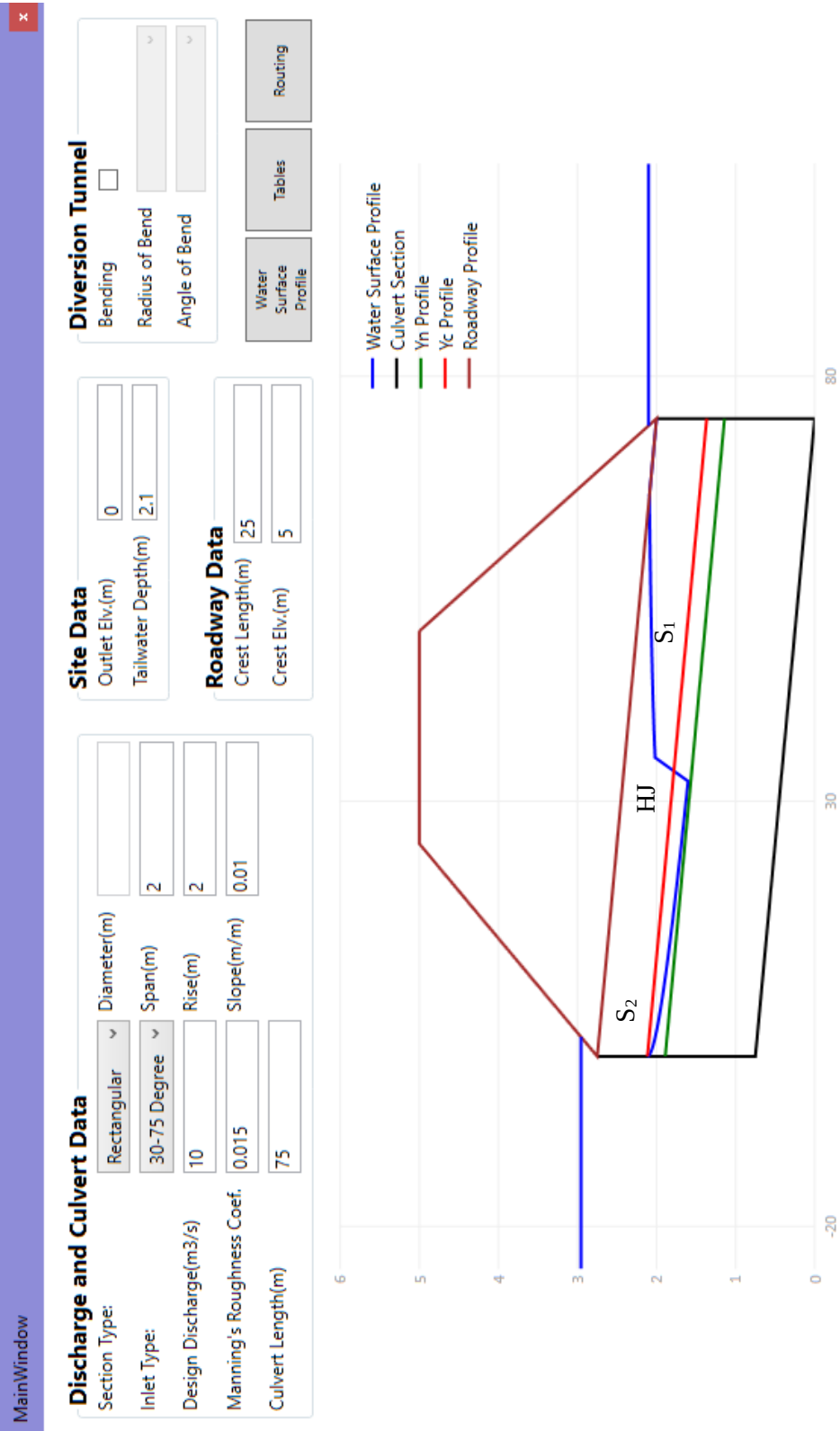


Table 4.27 Case-4 Rectangular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	10.00	2.96	INLET	1.14	1.37	2.00	2.10	2.50	8.98	66.02
HY-8	10.00	2.89	INLET	1.14	1.37	2.00	2.10	2.50	15.49	59.51

Table 4.28 Case-4 Rectangular section, water surface profile output

$\Sigma \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	1.37	2.73	3.66	0.58	0.015	0.0063
0.03	1.36	2.71	3.69	0.58	0.015	0.0064
0.13	1.35	2.69	3.71	0.57	0.015	0.0065
0.29	1.34	2.67	3.74	0.57	0.015	0.0066
0.54	1.33	2.65	3.77	0.57	0.015	0.0068
0.87	1.32	2.63	3.80	0.57	0.015	0.0069
1.31	1.31	2.61	3.83	0.57	0.015	0.0070
1.85	1.30	2.59	3.86	0.56	0.015	0.0072
2.52	1.29	2.57	3.89	0.56	0.015	0.0073
3.34	1.28	2.55	3.92	0.56	0.015	0.0075
4.33	1.27	2.53	3.95	0.56	0.015	0.0076
5.51	1.26	2.51	3.98	0.56	0.015	0.0078
6.93	1.25	2.49	4.01	0.55	0.015	0.0079
8.62	1.24	2.47	4.05	0.55	0.015	0.0081
10.67	1.23	2.45	4.08	0.55	0.015	0.0083
13.14	1.22	2.43	4.11	0.55	0.015	0.0085
16.16	1.21	2.41	4.15	0.55	0.015	0.0087
19.93	1.20	2.39	4.18	0.54	0.015	0.0088
24.74	1.19	2.37	4.22	0.54	0.015	0.0090
32.35	1.17	2.35	4.26	0.54	0.015	0.0093
35.14	1.62	3.24	3.09	0.62	0.015	0.0041
35.34	1.62	3.24	3.08	0.62	0.015	0.0041
35.82	1.63	3.26	3.07	0.62	0.015	0.0040
36.51	1.64	3.28	3.05	0.62	0.015	0.0039
37.21	1.65	3.30	3.03	0.62	0.015	0.0039
37.93	1.66	3.32	3.01	0.62	0.015	0.0038
.	.	.	.	.	.	.
64.23	1.98	3.96	2.53	0.66	0.015	0.0025
65.12	1.99	3.98	2.51	0.67	0.015	0.0024
66.02	2.00	4.00	2.50	0.67	0.015	0.0024
75.00	2.00	4.00	2.50	0.67	0.015	0.0024



Figure 4.13 Case-4 Tunnel section, water surface profile

Table 4.29 Case-4 Tunnel section, summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	100.00	36.15	INLET	2.18	3.85	5.00	10.00	5.09	394.66	1605.3
HY-8	100.00	36.06	INLET	2.18	3.85	5.00	10.00	5.09	369.68	1630.3

Table 4.30 Case-4 Tunnel section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	3.85	16.24	6.16	1.52	0.011	0.0026
0.00	3.84	16.20	6.17	1.51	0.011	0.0026
0.02	3.83	16.16	6.19	1.51	0.011	0.0027
0.04	3.82	16.11	6.21	1.51	0.011	0.0027
0.07	3.81	16.07	6.22	1.51	0.011	0.0027
0.11	3.80	16.03	6.24	1.51	0.011	0.0027
0.16	3.79	15.99	6.26	1.51	0.011	0.0027
0.22	3.78	15.94	6.27	1.51	0.011	0.0027
0.29	3.77	15.90	6.29	1.51	0.011	0.0028
.	.	.	.	.	.	.
1571.08	4.30	17.96	5.57	1.51	0.011	0.0022
1571.38	4.31	18.00	5.56	1.51	0.011	0.0022
1571.70	4.32	18.03	5.55	1.51	0.011	0.0021
1572.01	4.33	18.07	5.53	1.51	0.011	0.0021
1572.34	4.34	18.10	5.52	1.51	0.011	0.0021
1572.66	4.35	18.13	5.51	1.51	0.011	0.0021
1573.00	4.36	18.17	5.50	1.51	0.011	0.0021
1573.33	4.37	18.20	5.49	1.51	0.011	0.0021
1573.68	4.38	18.23	5.48	1.51	0.011	0.0021
1574.03	4.39	18.27	5.47	1.50	0.011	0.0021
1574.38	4.40	18.30	5.46	1.50	0.011	0.0021
.	.	.	.	.	.	.
1599.15	4.91	19.55	5.11	1.36	0.011	0.0021
1599.79	4.92	19.57	5.11	1.36	0.011	0.0021
1600.44	4.93	19.58	5.11	1.35	0.011	0.0021
1601.09	4.94	19.59	5.10	1.34	0.011	0.0021
1601.76	4.95	19.60	5.10	1.33	0.011	0.0021
1602.44	4.96	19.61	5.10	1.32	0.011	0.0022
1603.13	4.97	19.62	5.10	1.31	0.011	0.0022
1603.84	4.98	19.63	5.10	1.30	0.011	0.0022
1604.57	4.99	19.63	5.09	1.29	0.011	0.0022
2000.00	5.00	19.63	5.09	1.25	0.011	0.0023

4.3.5 Case-5

Case-5 is the first condition analyzed for the outlet control. The structure has a mild slope and both ends are free. This condition is obtained under mild slope conditions. The flow profile starts from downstream with the critical depth and proceeds to upstream. Since the flow is subcritical and does not assure full flow, the headwater is found with the gradually varied flow computations.

The flow profile through the conduit is shown in Figures 4.14 through 4.16 in which the flow profiles, such as M_2 are presented on the figure. The results of the analyses are outlined in Tables 4.31 through 4.36. The results of the C-PAS are relatively in good agreement with those of HY-8.

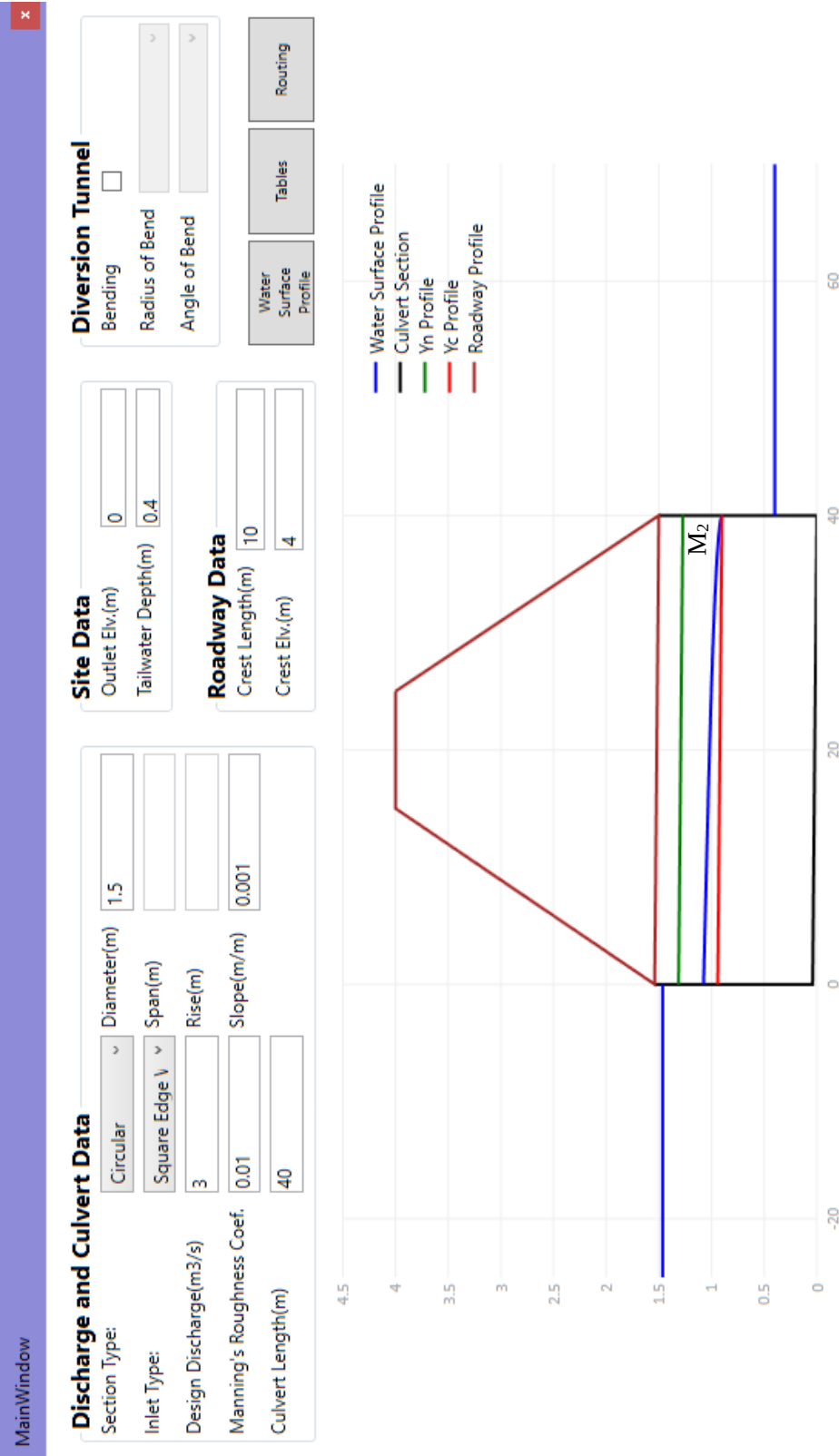


Figure 4.14 Case-5 Circular section, water surface profile

Table 4.31 Case-5 Circular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	3.00	1.46	OUTLET	1.27	0.90	0.90	0.40	2.71	0.00	40.00
HY-8	3.00	1.48	OUTLET	1.28	0.90	0.90	0.40	2.72	0.00	40.00

Table 4.32 Case-5 Circular section, water surface profile output

$\Sigma\Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	1.04	1.30	2.30	0.44	0.010	0.0016
8.39	1.02	1.28	2.34	0.44	0.010	0.0016
16.69	1.01	1.26	2.38	0.44	0.010	0.0017
23.45	0.99	1.24	2.42	0.44	0.010	0.0018
28.84	0.98	1.22	2.46	0.43	0.010	0.0019
33.02	0.96	1.20	2.51	0.43	0.010	0.0019
36.12	0.95	1.17	2.55	0.43	0.010	0.0020
38.26	0.93	1.15	2.60	0.42	0.010	0.0021
39.52	0.92	1.13	2.65	0.42	0.010	0.0022
40.00	0.90	1.11	2.71	0.42	0.010	0.0024

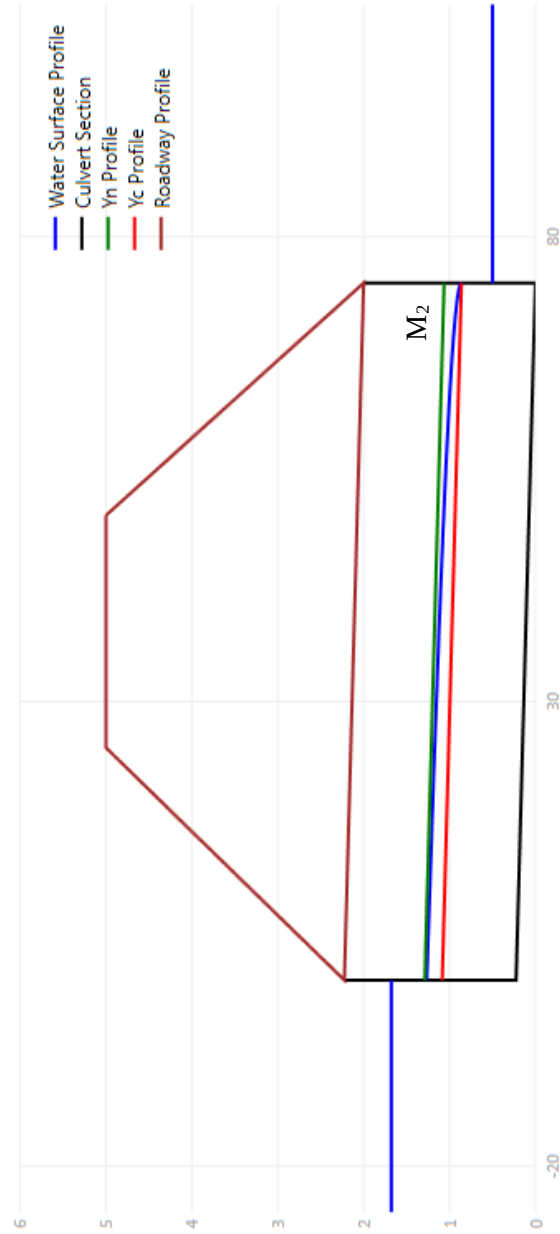
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Figure 4.15 Case-5 Rectangular section, water surface profile

Table 4.33 Case-5 Rectangular section, culvert summary table

Software	Q	HW	Flow Type	y_n	y_c	y_o	TW	u_o	L_f	L_{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	5.00	1.68	OUTLET	1.06	0.86	0.86	0.50	2.91	0.00	75.00
HY-8	5.00	1.68	OUTLET	1.06	0.86	0.86	0.50	2.91	0.00	75.00

Table 4.34 Case-5 Rectangular section, water surface profile output

$\Sigma \Delta x$	y	A	u	R	n	S_f
m	m	m ²	m/s	m		m/m
0.00	1.04	2.08	2.40	0.51	0.015	0.0032
22.27	1.03	2.05	2.44	0.51	0.015	0.0033
37.89	1.01	2.02	2.47	0.50	0.015	0.0034
48.59	1.00	1.99	2.51	0.50	0.015	0.0036
56.29	0.98	1.96	2.55	0.50	0.015	0.0037
61.97	0.97	1.93	2.59	0.49	0.015	0.0039
66.20	0.95	1.90	2.63	0.49	0.015	0.0041
69.34	0.94	1.87	2.67	0.48	0.015	0.0042
71.62	0.92	1.84	2.72	0.48	0.015	0.0044
73.22	0.91	1.81	2.76	0.48	0.015	0.0046
74.26	0.89	1.78	2.81	0.47	0.015	0.0048
74.83	0.88	1.75	2.86	0.47	0.015	0.0051
75.00	0.86	1.72	2.91	0.46	0.015	0.0053



Figure 4.16 Case-5 Tunnel section, water surface profile

Table 4.35 Case-5 Tunnel section, summary table

Software	Q	HW	Flow Type	y_n	y_c	y_o	TW	u_o	L_f	L_{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	30.00	5.15	OUTLET	2.38	2.07	2.07	1.00	3.91	0.00	2000.00
HY-8	30.00	5.03	OUTLET	2.37	2.07	2.07	1.00	3.91	0.00	2000.00

Table 4.36 Case-5 Tunnel section, water surface profile output

$\Sigma \Delta x$	y	A	u	R	n	S_f
m	m	m ²	m/s	m		m/m
0.00	2.38	9.24	3.25	1.21	0.011	0.0010
1228.87	2.37	9.16	3.27	1.21	0.011	0.0010
1519.92	2.35	9.09	3.30	1.20	0.011	0.0010
1652.28	2.34	9.01	3.33	1.20	0.011	0.0011
1734.56	2.32	8.94	3.36	1.19	0.011	0.0011
1792.30	2.31	8.86	3.38	1.19	0.011	0.0011
1835.47	2.29	8.79	3.41	1.18	0.011	0.0011
1869.01	2.28	8.71	3.44	1.18	0.011	0.0012
1895.69	2.26	8.64	3.47	1.17	0.011	0.0012
1917.26	2.25	8.57	3.50	1.17	0.011	0.0012
1934.86	2.23	8.49	3.53	1.16	0.011	0.0012
1949.29	2.22	8.42	3.56	1.15	0.011	0.0013
1961.14	2.20	8.34	3.60	1.15	0.011	0.0013
1970.85	2.19	8.27	3.63	1.14	0.011	0.0013
1978.74	2.17	8.19	3.66	1.14	0.011	0.0014
1985.08	2.16	8.12	3.70	1.13	0.011	0.0014
1990.08	2.14	8.04	3.73	1.13	0.011	0.0014
1993.91	2.13	7.97	3.76	1.12	0.011	0.0015
1996.70	2.11	7.90	3.80	1.12	0.011	0.0015
1998.59	2.10	7.82	3.84	1.11	0.011	0.0015
1999.66	2.08	7.75	3.87	1.10	0.011	0.0016
2000.00	2.07	7.67	3.91	1.10	0.011	0.0016

4.3.6 Case-6

This condition is the same as Case-5, except the outlet depth. Tailwater depth is chosen as a higher value than the critical depth to show how structure operates depending on tailwater depth. Again, both ends are free as stated in Case-5 and the culvert or tunnel has a subcritical flow inside with a mild slope. Since the barrel

length is not long enough, the flow couldn't reach to normal depth and M_1 profile is partially developed for the rectangular culvert and diversion tunnel example.

The flow profile through the conduit is shown in Figures 4.17 through 4.19 in which the flow profiles, such as M_1 and M_2 are presented on the figure. The results of the analyses are outlined in Tables 4.37 through 4.42. The results of the C-PAS are relatively in good agreement with those of HY-8.

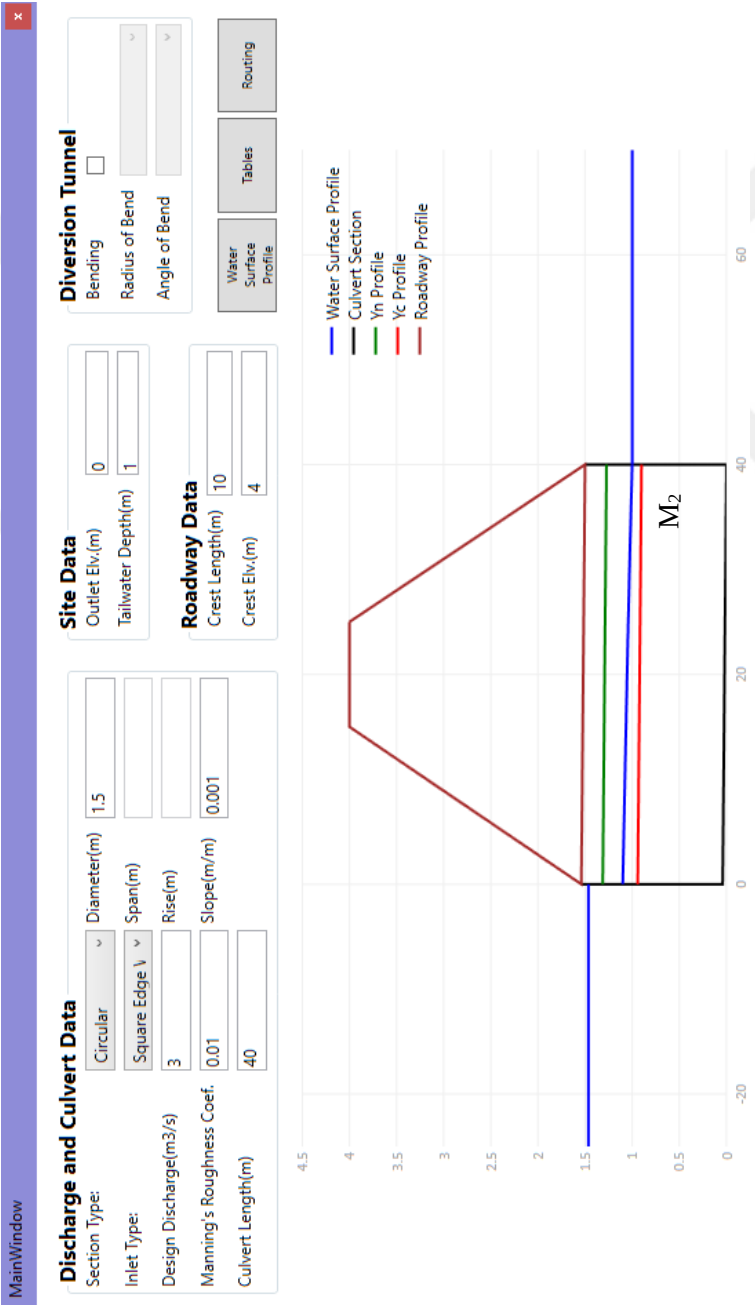


Figure 4.17 Case-6 Circular section, water surface profile

Table 4.37 Case-6 Circular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	3.00	1.46	OUTLET	1.27	0.90	1.00	1.00	2.40	0.00	40.00
HY-8	3.00	1.49	OUTLET	1.28	0.90	1.00	1.00	2.40	0.00	40.00

Table 4.38 Case-6 Circular section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	1.06	1.33	2.25	0.45	0.010	0.0015
11.79	1.05	1.31	2.28	0.44	0.010	0.0015
23.02	1.03	1.29	2.32	0.44	0.010	0.0016
32.35	1.02	1.27	2.36	0.44	0.010	0.0017
40.00	1.00	1.25	2.40	0.44	0.010	0.0017



Figure 4.18 Case-6 Rectangular section, water surface profile

Table 4.39 Case-6 Rectangular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	5.00	1.70	OUTLET	1.06	0.86	1.20	1.20	2.08	0.00	75.00
HY-8	5.00	1.70	OUTLET	1.06	0.86	1.20	1.20	2.08	0.00	75.00

Table 4.40 Case-6 Rectangular section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	1.11	2.22	2.25	0.53	0.015	0.0027
0.47	1.13	2.25	2.22	0.53	0.015	0.0026
19.18	1.14	2.28	2.19	0.53	0.015	0.0025
35.35	1.16	2.31	2.16	0.54	0.015	0.0024
49.76	1.17	2.34	2.14	0.54	0.015	0.0023
62.87	1.19	2.37	2.11	0.54	0.015	0.0023
75.00	1.20	2.40	2.08	0.55	0.015	0.0022

MainWindow

Discharge and Culvert Data

Section Type:

Circular

Diameter(m)

5

Inlet Type:

Groove End W

Span(m)

2

Design Discharge(m³/s)

30

Rise(m)

2

Manning's Roughness Coef.

0.011

Slope(m/m)

0.001

Culvert Length(m)

2000

Site Data

Outlet Elv.(m)

0

Tailwater Depth(m)

3

Roadway Data

Crest Length(m)

2000

Crest Elv.(m)

20

Diversion Tunnel

Bending

☒

Radius of Bend

2

Angle of Bend

45

Water Surface Profile

Tables

Routing

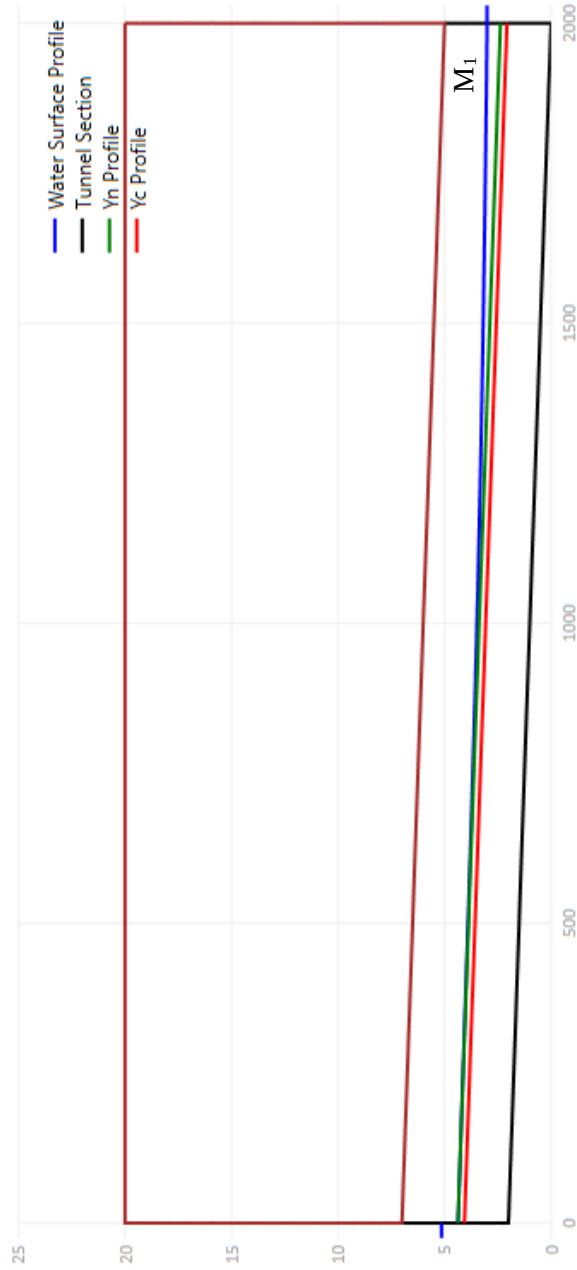


Figure 4.19 Case-6 Tunnel section, water surface profile

Table 4.41 Case-6 Tunnel section, summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	30.00	5.15	OUTLET	2.38	2.07	3.00	3.00	2.44	0.00	2000.00
HY-8	30.00	5.03	OUTLET	2.37	2.07	3.00	3.00	2.44	0.00	2000.00

Table 4.42 Case-6 Tunnel section, water surface profile output

$\Sigma\Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	2.37	9.17	3.27	1.21	0.011	0.0010
259.56	2.38	9.24	3.25	1.21	0.011	0.0010
521.42	2.40	9.32	3.22	1.22	0.011	0.0010
667.27	2.42	9.39	3.19	1.22	0.011	0.0009
771.11	2.43	9.47	3.17	1.23	0.011	0.0009
853.26	2.45	9.54	3.14	1.23	0.011	0.0009
922.17	2.46	9.62	3.12	1.24	0.011	0.0009
982.16	2.48	9.69	3.10	1.24	0.011	0.0009
1035.74	2.49	9.77	3.07	1.25	0.011	0.0009
1084.48	2.51	9.84	3.05	1.25	0.011	0.0008
1129.45	2.52	9.92	3.02	1.26	0.011	0.0008
1171.38	2.54	9.99	3.00	1.26	0.011	0.0008
1210.84	2.55	10.07	2.98	1.27	0.011	0.0008
1248.23	2.57	10.14	2.96	1.27	0.011	0.0008
1283.86	2.58	10.22	2.94	1.27	0.011	0.0008
1317.98	2.60	10.29	2.91	1.28	0.011	0.0007
1350.81	2.61	10.37	2.89	1.28	0.011	0.0007
1382.49	2.63	10.44	2.87	1.29	0.011	0.0007
1413.16	2.64	10.52	2.85	1.29	0.011	0.0007
1442.94	2.66	10.59	2.83	1.30	0.011	0.0007
1471.92	2.67	10.67	2.81	1.30	0.011	0.0007
1500.18	2.69	10.74	2.79	1.31	0.011	0.0007
1527.79	2.70	10.82	2.77	1.31	0.011	0.0006
1554.81	2.72	10.89	2.75	1.31	0.011	0.0006
.	.	.	.	.	.	.
1891.63	2.93	11.93	2.51	1.37	0.011	0.0005
1913.66	2.94	12.01	2.50	1.37	0.011	0.0005
1935.50	2.96	12.08	2.48	1.38	0.011	0.0005
1957.17	2.97	12.15	2.47	1.38	0.011	0.0005
1978.66	2.99	12.23	2.45	1.38	0.011	0.0005
2000.00	3.00	12.30	2.44	1.39	0.011	0.0005

4.3.7 Case-7

This condition is one of the outlet control conditions with an almost full barrel length. Culvert or tunnel operates as full flow. The FHWA approximate method is used to find the outlet depth. After obtaining the outlet depth, gradually varied flow calculations are proceeded to find the point where flow intersects with the culvert top. Headwater elevation is found from the energy equation.

The flow profile through the conduit is shown in Figures 4.20 through 4.22 in which the flow profiles, such as M_2 are presented on the figure. The results of the analyses are outlined in Tables 4.43 through 4.48. The results of the C-PAS are relatively in good agreement with those of HY-8.

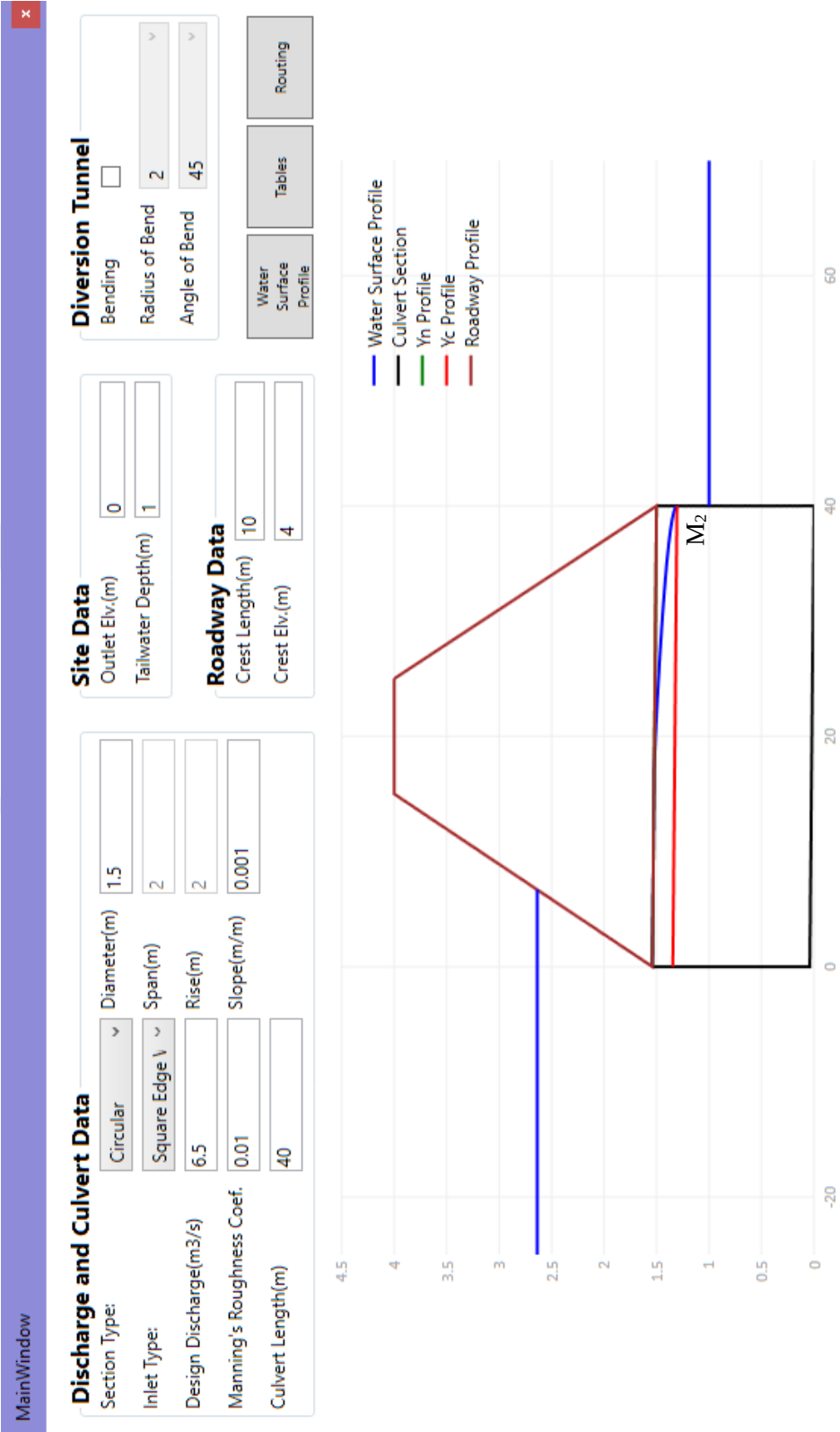


Figure 4.20 Case-7 Circular section, water surface profile

Table 4.43 Case-7 Circular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	6.50	2.79	OUTLET	1.50	1.31	1.31	1.00	3.98	17.47	22.53
HY-8	6.50	2.79	OUTLET	1.50	1.30	1.30	1.00	3.98	17.99	22.01

Table 4.44 Case-7 Circular section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	1.50	1.77	3.68	0.38	0.010	0.0050
2.48	1.50	1.77	3.68	0.38	0.010	0.0050
9.98	1.50	1.77	3.68	0.38	0.010	0.0050
13.72	1.50	1.77	3.68	0.38	0.010	0.0050
17.47	1.50	1.77	3.68	0.38	0.010	0.0050
21.18	1.49	1.76	3.68	0.40	0.010	0.0046
24.23	1.47	1.76	3.70	0.41	0.010	0.0045
26.98	1.46	1.75	3.71	0.42	0.010	0.0044
29.46	1.44	1.74	3.73	0.42	0.010	0.0044
31.67	1.43	1.73	3.75	0.43	0.010	0.0043
33.62	1.41	1.72	3.77	0.43	0.010	0.0043
35.31	1.40	1.71	3.79	0.44	0.010	0.0043
36.74	1.38	1.70	3.82	0.44	0.010	0.0043
37.91	1.37	1.69	3.85	0.44	0.010	0.0044
38.82	1.35	1.68	3.88	0.45	0.010	0.0044



Figure 4.21 Case-7 Rectangular section, water surface profile

Table 4.45 Case-7 Rectangular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	13.00	2.87	OUTLET	2.00	1.63	1.63	1.20	4.00	16.91	58.09
HY-8	13.00	2.69	OUTLET	2.00	1.63	1.63	1.20	4.00	20.88	54.12

Table 4.46 Case-7 Rectangular section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	2.00	4.00	3.25	0.67	0.015	0.0041
4.10	2.00	4.00	3.25	0.67	0.015	0.0041
10.50	2.00	4.00	3.25	0.67	0.015	0.0041
16.91	2.00	4.00	3.25	0.67	0.015	0.0041
23.06	1.99	3.97	3.27	0.67	0.015	0.0041
28.69	1.97	3.94	3.30	0.66	0.015	0.0042
33.81	1.96	3.91	3.32	0.66	0.015	0.0043
38.48	1.94	3.88	3.35	0.66	0.015	0.0044
42.74	1.93	3.85	3.37	0.66	0.015	0.0045
46.61	1.91	3.82	3.40	0.66	0.015	0.0046
50.14	1.90	3.79	3.43	0.65	0.015	0.0046
53.35	1.88	3.76	3.45	0.65	0.015	0.0047
56.25	1.87	3.73	3.48	0.65	0.015	0.0048
58.89	1.85	3.70	3.51	0.65	0.015	0.0049
61.27	1.84	3.67	3.54	0.65	0.015	0.0050
63.40	1.82	3.64	3.57	0.65	0.015	0.0051
65.32	1.81	3.61	3.60	0.64	0.015	0.0052
67.03	1.79	3.58	3.63	0.64	0.015	0.0053
68.54	1.78	3.55	3.66	0.64	0.015	0.0055
69.86	1.76	3.52	3.69	0.64	0.015	0.0056
71.02	1.75	3.49	3.72	0.64	0.015	0.0057
72.01	1.73	3.46	3.75	0.63	0.015	0.0058
72.84	1.72	3.43	3.79	0.63	0.015	0.0059
73.52	1.70	3.40	3.82	0.63	0.015	0.0061
74.07	1.69	3.37	3.85	0.63	0.015	0.0062
74.49	1.67	3.34	3.89	0.63	0.015	0.0064
74.78	1.66	3.31	3.92	0.62	0.015	0.0065
74.95	1.64	3.28	3.96	0.62	0.015	0.0066
75.00	1.63	3.25	4.00	0.62	0.015	0.0068

MainWindow

Discharge and Culvert Data

Section Type:

Circular

Diameter(m)

5

Inlet Type:

Groove End W

Span(m)

2

Design Discharge(m³/s)

100

Rise(m)

2

Manning's Roughness Coef.

0.011

Culvert Length(m)

2000

Site Data

Outlet Elv.(m)

0

Tailwater Depth(m)

3

Roadway Data

Crest Length(m)

2000

Crest Elv.(m)

20

Diversion Tunnel

Bending

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Radius of Bend

2

Angle of Bend

45

Water Surface Profile

Tables

Routing

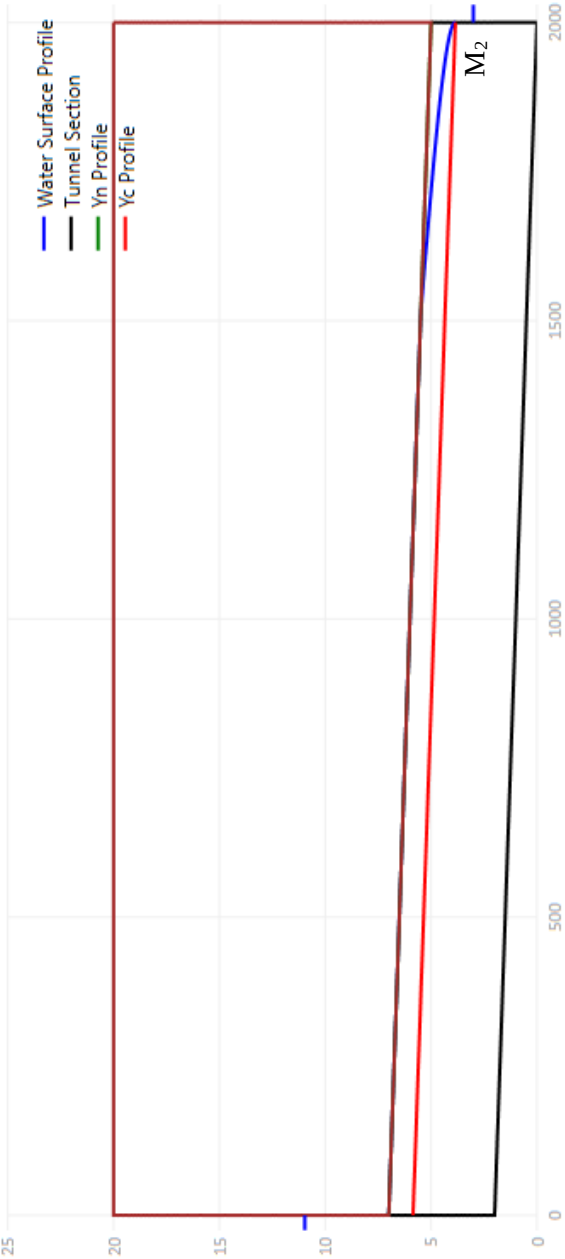


Figure 4.22 Case-7 Tunnel section, water surface profile

Table 4.47 Case-7 Tunnel section, summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	100.00	10.97	OUTLET	5.00	3.85	3.85	3.00	6.16	1506.35	493.65
HY-8	100.00	10.58	OUTLET	5.00	3.85	3.85	3.00	6.16	1516.03	483.97

Table 4.48 Case-7 Tunnel section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	5.00	19.63	5.09	1.25	0.011	0.0023
7.29	5.00	19.63	5.09	1.25	0.011	0.0023
18.56	5.00	19.63	5.09	1.25	0.011	0.0023
29.84	5.00	19.63	5.09	1.25	0.011	0.0023
41.11	5.00	19.63	5.09	1.25	0.011	0.0023
52.38	5.00	19.63	5.09	1.25	0.011	0.0023
63.65	5.00	19.63	5.09	1.25	0.011	0.0023
.	.	.	.	.	.	.
1506.35	5.00	19.63	5.09	1.25	0.011	0.0023
1517.77	4.99	19.63	5.09	1.28	0.011	0.0023
1529.13	4.98	19.63	5.10	1.30	0.011	0.0022
1540.48	4.96	19.61	5.10	1.32	0.011	0.0022
1551.81	4.95	19.60	5.10	1.33	0.011	0.0021
1563.11	4.93	19.58	5.11	1.35	0.011	0.0021
1574.36	4.92	19.57	5.11	1.36	0.011	0.0021
1585.57	4.90	19.55	5.12	1.37	0.011	0.0021
1596.71	4.89	19.53	5.12	1.37	0.011	0.0021
1607.78	4.87	19.50	5.13	1.38	0.011	0.0021
1618.77	4.86	19.48	5.13	1.39	0.011	0.0021
1629.68	4.84	19.45	5.14	1.40	0.011	0.0020
1640.49	4.83	19.43	5.15	1.40	0.011	0.0020
1651.20	4.81	19.40	5.15	1.41	0.011	0.0020
1661.81	4.80	19.37	5.16	1.41	0.011	0.0020
1672.30	4.78	19.34	5.17	1.42	0.011	0.0020
1682.67	4.77	19.31	5.18	1.43	0.011	0.0020
1692.92	4.75	19.28	5.19	1.43	0.011	0.0020
.	.	.	.	.	.	.
1998.10	3.93	16.55	6.04	1.52	0.011	0.0025
1998.79	3.91	16.49	6.06	1.52	0.011	0.0025
1999.32	3.90	16.43	6.09	1.52	0.011	0.0026
1999.70	3.88	16.37	6.11	1.52	0.011	0.0026
1999.93	3.87	16.30	6.13	1.52	0.011	0.0026
2000.00	3.85	16.24	6.16	1.52	0.011	0.0026

4.3.8 Case-8

The last and the classical condition occurs in the outlet control is full barrel flow. Both ends are submerged, and the barrel is exposed to pressurized flow. Headwater elevation is found by the energy equation and the tailwater elevation governs the outlet depth.

The flow profile through the conduit is shown in Figures 4.23 through 4.25. The results of the analyses are outlined in Tables 4.49 through 4.54. The results of the C-PAS are relatively in good agreement with those of HY-8.



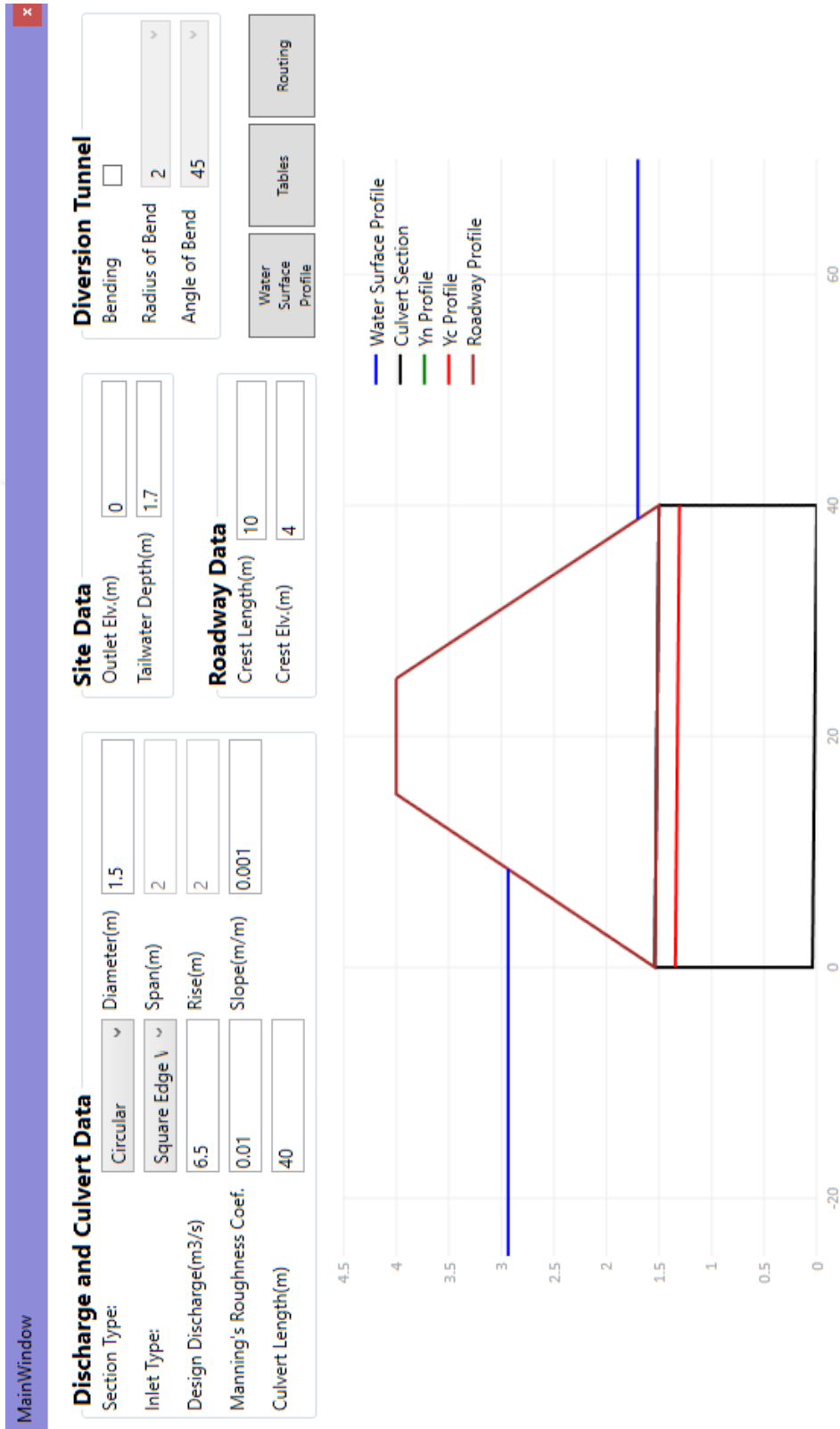


Figure 4.23 Case-8 Circular section, water surface profile

Table 4.49 Case-8 Circular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	6.50	2.93	OUTLET	1.50	1.31	1.50	1.70	3.68	40.00	0.00
HY-8	6.50	2.93	OUTLET	1.50	1.30	1.50	1.70	3.68	40.00	0.00

Table 4.50 Case-8 Circular section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	1.50	1.77	3.68	0.38	0.010	0.0050
40.00	1.50	1.77	3.68	0.38	0.010	0.0050

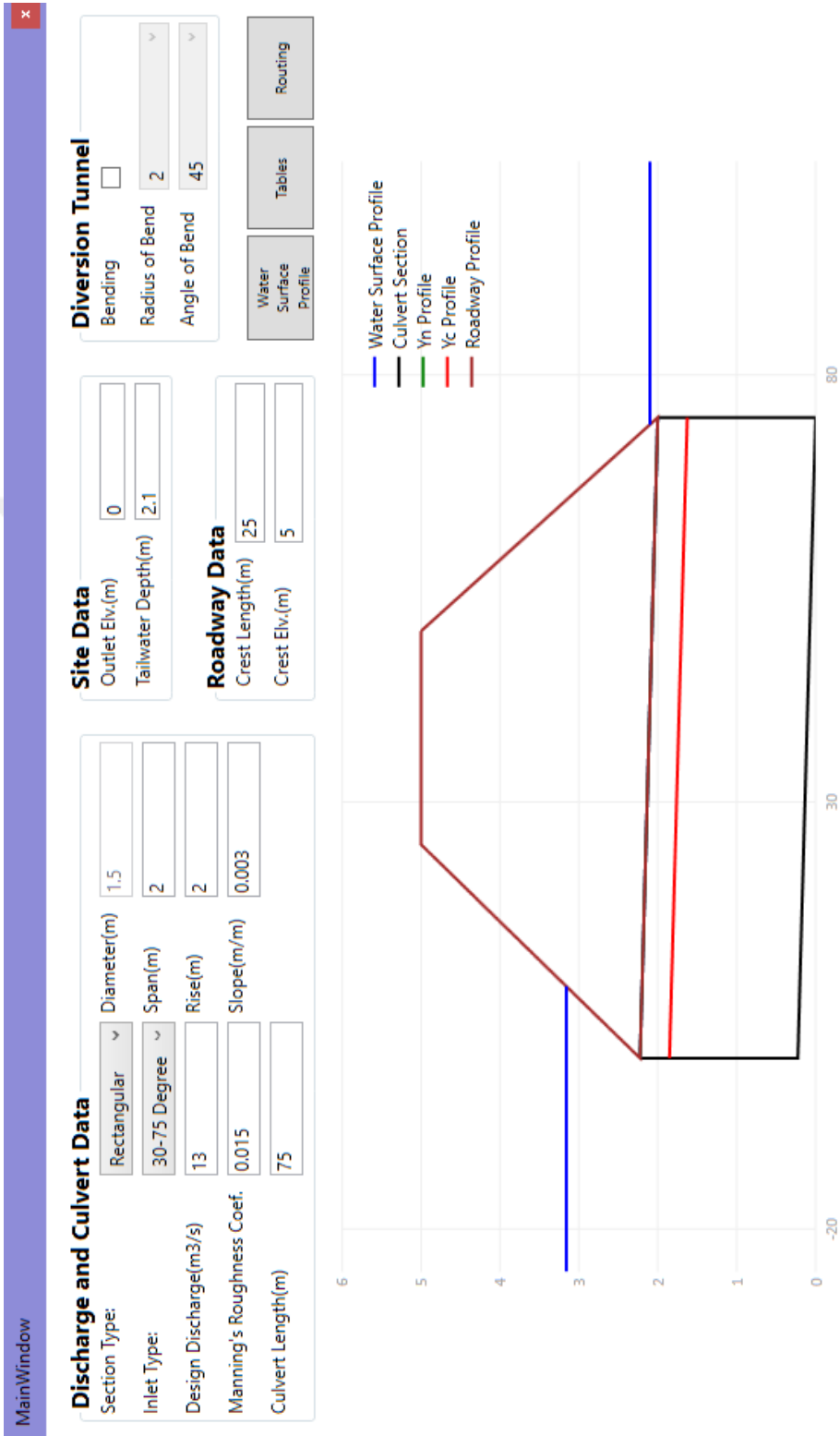


Figure 4.24 Case-8 Rectangular section, water surface profile

Table 4.51 Case-8 Rectangular section, culvert summary table

Software	Q	HW	Flow Type	y _n	y _c	y _o	TW	u _o	L _f	L _{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	13.00	3.16	OUTLET	2.00	1.63	2.00	2.10	3.25	75.00	0.00
HY-8	13.00	3.30	OUTLET	2.00	1.63	2.00	2.10	3.25	75.00	0.00

Table 4.52 Case-8 Rectangular section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S _f
m	m	m ²	m/s	m		m/m
0.00	2.00	4.00	3.25	0.67	0.015	0.0041
75.00	2.00	4.00	3.25	0.67	0.015	0.0041



Table 4.53 Case-8 Tunnel section, summary table

Software	Q	HW	Flow Type	y_n	y_c	y_o	TW	u_o	L_f	L_{fr}
	m ³ /s	m		m	m	m	m	m/s	m	m
C-PAS	100.00	12.54	OUTLET	5.00	3.85	5.00	6.00	5.09	2000.00	0.00
HY-8	100.00	12.22	OUTLET	5.00	3.85	5.00	600	5.09	2000.00	0.00

Table 4.54 Case-8 Tunnel section, water surface profile output

$\sum \Delta x$	y	A	u	R	n	S_f
m	m	m ²	m/s	m		m/m
0.00	5.00	19.63	5.09	1.25	0.011	0.0023
2000.00	5.00	19.63	5.09	1.25	0.011	0.0023

Storage routing procedure can be examined when the culvert is operating as a pressurized flow because of the stored reservoir in the upstream. An application for Case-8 has been conducted for the tunnel section and the calculated headwater depth for the peak inflow is compared with the steady flow solution performed using the peak inflow value of 100 m³/s (See Table 4.53). Data input to the software can be seen in Table 4.55. The inflow and outflow hydrographs are presented in Figure 4.26, the comparison between steady and unsteady solutions are given in Table 4.56, and the routing calculations are given in Table 4.57. As expected, the peak outflow intersects the falling limb of the inflow hydrograph. Furthermore, the case with routing would correspond to lower headwater elevation compared to the case of steady discharge of 100 m³/s (44% decrease). Therefore, computation of the maximum reservoir level or determination of roadway crest elevation using routing procedure would lead to an economical solution.

Table 4.55 Data input for routing procedure

Δt (hr)	0.167	TW (m)	6.00
D (m)	5.00	Reservoir Volume at t_0 (m ³)	100000.00
A (m ²)	19.63	a (area coef.)	300.00
I_p (m ³ /s)	100.000	b (area coef.)	70.00
t_p (hr)	1.000	c (area coef.)	5.00

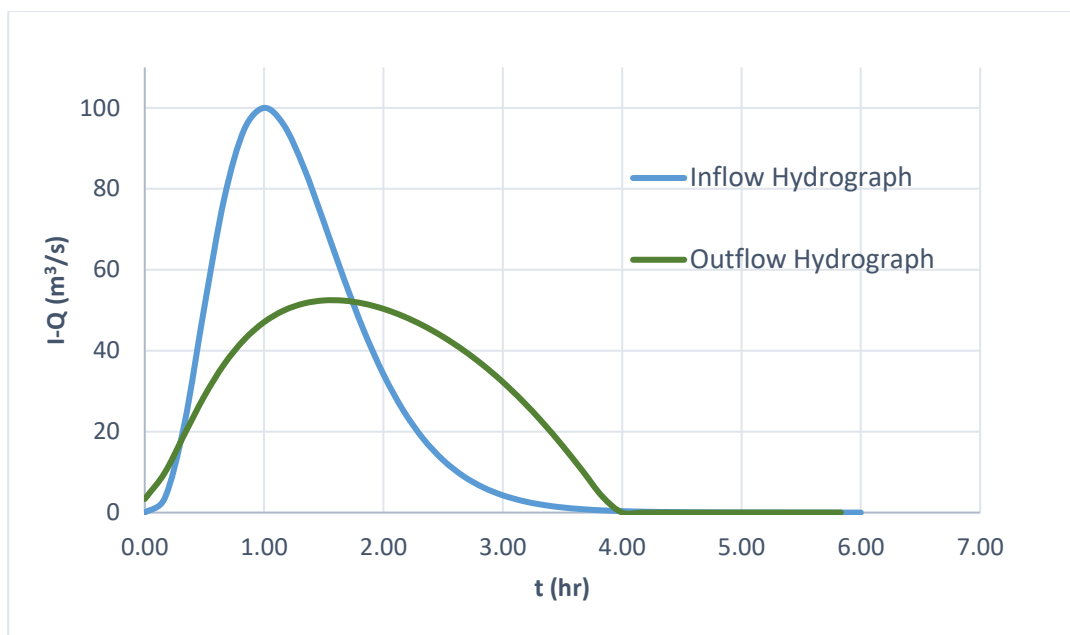


Figure 4.26 Inflow-Outflow Hydrographs

Table 4.56 Comparison of steady and unsteady flow analyses in terms of headwater

Flow Condition	Steady State	Unsteady State
Calculated HW for Q=100 m ³ /s Incoming Flow	12.94 m	7.27 m

Table 4.57 Output of routing calculations

t (hr)	Δt (hr)	I (m ³ /s)	I _{av} (m ³ /s)	V _{in} (m ³)	Q _{assumed} (m ³ /s)	H _t (m)	Q _{eq} (m ³ /s)	V _{out} (m ³)	V _{acc} (m ³)	V _t (m ³)	V _i (m ³)
0.00	0.17	0.00	0.00	0.00	8.12	6.05	8.12	4869.92	-4869.92	95130.08	95130.08
0.17	0.17	3.49	1.75	1047.81	3.35	6.01	5.73	3440.97	-2393.16	92736.92	92736.92
0.33	0.17	22.05	12.77	7663.13	9.79	6.07	6.57	3941.69	96458.36	96458.36	96458.36
0.50	0.17	50.86	36.46	21874.51	19.38	6.26	14.58	8749.61	13124.91	109583.27	109583.27
0.67	0.17	77.69	64.28	38565.79	28.81	6.58	24.09	14456.53	24109.26	133692.53	133692.53
0.83	0.17	94.67	86.18	51707.05	36.70	6.93	32.76	19653.34	32053.71	165746.24	165746.24
1.00	0.17	100.00	97.33	58400.46	42.74	7.27	39.72	23832.00	34568.45	200314.69	200314.69
1.17	0.17	95.71	97.86	58714.19	47.07	7.54	44.90	26940.78	31773.41	232088.11	232088.11
1.33	0.17	85.23	90.47	54284.14	49.96	7.73	48.51	29106.31	25177.83	257265.94	257265.94
1.50	0.17	71.83	78.53	47118.86	51.67	7.85	50.81	30487.74	16631.13	273897.07	273897.07
1.67	0.17	57.96	64.89	38936.45	52.42	7.91	52.04	31226.83	7709.62	281606.69	281606.69
1.83	0.17	45.15	51.55	30932.38	52.37	7.90	52.40	31437.30	-504.92	281101.77	281101.77
2.00	0.17	34.16	39.66	23794.18	51.65	7.85	52.01	31206.18	-7412.00	273689.77	273689.77
2.17	0.17	25.23	29.70	17818.09	50.34	7.76	51.00	30597.83	-12779.75	260910.03	260910.03
2.33	0.17	18.25	21.74	13043.10	48.52	7.63	49.43	29657.90	-16614.79	244295.23	244295.23
2.50	0.17	12.96	15.61	9363.59	46.21	7.48	47.36	28416.41	-19052.82	225242.42	225242.42
2.67	0.17	9.07	11.02	6609.61	43.43	7.31	44.82	26890.34	-20280.73	204961.69	204961.69
2.83	0.17	6.26	7.66	4597.26	40.19	7.12	41.81	25085.63	-20488.37	184473.32	184473.32
3.00	0.17	4.26	5.26	3156.23	36.47	6.92	38.33	22999.21	-19842.98	164630.33	164630.33
3.17	0.17	2.88	3.57	2141.98	32.26	6.72	34.37	20621.51	-18479.53	146150.80	146150.80
3.33	0.17	1.92	2.40	1438.69	27.54	6.53	29.90	17940.27	-16501.58	129649.22	129649.22
3.50	0.17	1.27	1.60	957.36	22.29	6.34	24.91	14946.86	-13989.50	115659.72	115659.72
3.67	0.17	0.83	1.05	631.73	16.54	6.19	19.41	11646.27	-11014.54	104645.17	104645.17
3.83	0.17	0.54	0.69	413.67	10.37	6.07	13.45	8071.89	-7658.21	96986.96	96986.96
4.00	0.17	0.35	0.45	269.00	4.00	6.01	7.19	4311.93	-4042.92	92944.03	92944.03
4.17	0.17	0.23	0.29	173.81	0.00	6.00	1.31	784.83	-611.02	92333.01	92333.01
4.33	0.17	0.15	0.19	111.64	0.00	6.00	0.13	77.70	33.95	92366.96	92366.96
4.50	0.17	0.09	0.12	71.32	0.00	6.00	0.20	122.04	-50.71	92316.25	92316.25
4.67	0.17	0.06	0.08	45.34	0.00	6.00	0.06	33.03	12.31	92328.56	92328.56
4.83	0.17	0.04	0.05	28.68	0.00	6.00	0.08	45.30	-16.62	92311.94	92311.94
5.00	0.17	0.02	0.03	18.07	0.00	6.00	0.02	13.37	4.70	92316.64	92316.64
5.17	0.17	0.01	0.02	11.34	0.00	6.00	0.03	17.43	-6.09	92310.55	92310.55
5.33	0.17	0.01	0.01	7.09	0.00	6.00	0.01	5.27	1.81	92312.36	92312.36
5.50	0.17	0.01	0.01	4.41	0.00	6.00	0.01	6.72	-2.30	92310.05	92310.05
5.67	0.17	0.00	0.00	2.74	0.00	6.00	0.00	2.04	0.70	92310.75	92310.75
5.83	0.17	0.00	0.00	1.69	0.00	6.00	0.00	2.57	-0.87	92309.87	92309.87
6.00	0.17	0.00	0.00	1.05	0.00	6.00	0.00	0.78	0.27	92310.14	92310.14

4.4 Design Application

A design application is also presented to size a culvert with reference to the specified roadway elevation using the software. By keeping some data input values constant, headwater values are calculated depending on the variables and the outputs are compared.

It is accepted that the freeboard will be 1 m below the road crest elevation as a limitation.

Assumed constant input data:

- $Q = 10 \text{ m}^3/\text{s}$
- $TW = 0.6 \text{ m}$
- Roadway crest length = 12 m
- Roadway crest elevation = 3 m
- Culvert length = 27 m
- $n = 0.011$ for circular section, 0.012 for box section

To find the best solution for the conduit, calculations are started with a circular section with a diameter of $D=2 \text{ m}$. A slope of 2% is tried first. Under these conditions, culvert operates as inlet control and the headwater causes overtopping. Second iteration is tried with a slope of 1%. In this way, culvert did not cause an overtopping, but the necessary freeboard is not satisfied. Third iteration is tried with section change. The same parameters are applied with rectangular section and again freeboard is not satisfied. To decrease the headwater level, the slope of the culvert is decreased to 0.1% for the other iteration. In this case, the required freeboard limit has been exceeded by 19 percent. Finally for the last iteration, the required freeboard is achieved by increasing the size of the culvert.

Table 4.58 Design application output

Trial No	Input				Output				Remarks		
	Q	Section Type	Size	S ₀	HW	Flow Type	y _n	y _c			
	m ³ /s			m/m	m		m	m			
1	10	Circular	D=2 m	0.02	3.08	Inlet	0.89	1.50	5.35	Headwater is higher than the crest elevation of the roadway. Overtopping.	X
2	10	Circular	D=2 m	0.01	2.92	Inlet	1.07	1.53	4.84	Headwater is 0.08 m below the crest elevation of the roadway. Freeboard is not satisfied.	X
3	10	Rectangular	2.0X2.0	0.01	2.62	Inlet	0.96	1.37	4.55	Headwater is 0.38 m below the crest elevation of the roadway. Freeboard is not satisfied.	X
4	10	Rectangular	2.0X2.0	0.001	2.38	Outlet	2.00	1.37	3.66	Headwater is 0.62 m below the crest elevation of the roadway. Freeboard is not satisfied.	X
5	10	Rectangular	2.5X2.5	0.001	2.00	Outlet	1.84	1.18	3.40	Headwater is 1.00 m below the crest elevation of the roadway. Freeboard is satisfied.	✓

4.5 Discussion of the Results

According to the output results, there are some issues that need to be considered. For the inlet control, since the slope is steep, the outlet velocity should be taken into account due to possible scour problems at the exit. For the submerged inlet conditions, if the design discharge value exceeds the culvert full capacity, culvert starts to operate under the outlet control. The overflow may also cause the road overtopping. The software checks if the calculated headwater is higher than the roadway crest elevation and gives a warning about overtopping. If this circumstance occurs, the designer should avoid the overtopping by increasing the size of the culvert. When the tailwater depth is higher than the critical depth, the flow goes through critical depth near the inlet and reaches supercritical flow, which is the assumption of inlet control. If the hydraulic jump occurs in the barrel, the culvert would pressurize along its length, causing the flow to operate like an orifice. As a result, the outlet of the structure should be designed in this manner. To decrease the energy, a hydraulic structure, such as a stilling basin can be used at the exit. Also, there are several factors to consider, such as supercritical flow along the conduit and hydraulic jump at the exit of the conduit. They will cause scouring in the downstream of the conduit, and the stability of the river will be influenced by this complex interacting system. Moreover, downstream sedimentation studies should be considered seriously, and a stilling basin on the downstream of the conduit should be built to muffle the hydraulic jump (Indrawati et al., 2018).

Full barrel flow is the easiest solution for hand calculations which is a condition from the outlet control analyses. The barrel flows full and operates under pressure. If the barrel is not full over its length but partially full, this circumstance causes a negative pressure along this free length. Therefore, reinforcement should be applied for this part or lining thickness should be increased. Air ventilation by means of a vertical shaft may also be considered.

CHAPTER 5

CONCLUSION

Culvert is a simple hydraulic structure but the flow conditions that are governed through it may be very complex due to various parameters. In the context of this research, design and flow analyses of a culvert and a diversion tunnel were carried out. At the beginning of the study, a literature review is considered. Previous studies and assumptions were examined. Analyses were conducted by taking into account all possible flow situations.

The C-PAS is developed as a user friendly software to perform these analyses faster and easier. The designer can easily input the flow rate and design the culvert for the required conditions. If the road level is restrictive, the culvert dimension may be increased or decreased by changing the slope. All possible flow conditions may be simulated by C-PAS and the related data outputs are shown to ensure preliminary design for the designer. A designer can evaluate the results in terms of hydraulic compliance and cost in an implicit manner by running the software sequentially. Use of the software is practical especially in case of risk-based design, which is based on evaluation of upstream and downstream water levels under a given design discharge for flood damage computations with respect to various dimensions of the conduit. This desktop application is, therefore, time-saving as it can ease successive applications rapidly .

Diversion tunnel structures can also be analyzed using C-PAS. As stated in previous chapters, tunnel structure is analyzed as a long span culvert. The designer should introduce the span length for the tunnel and the bending parameters, if exist.

In the scope of this study, circular and box sections are considered. To show the software process, an application study is carried out with different possible flow conditions.

In a future study, the software can be improved by adding some other section types, such as arch, horse-shoe or elliptical. Furthermore, energy dissipation process and downstream scour protection measures can be integrated into the software. Also, composite slope and multiple bend features may be added for the diversion tunnel analyses.



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SOURCE CODE OF THE SOFTWARE

```
using System;
using System.Collections.Generic;
using System.Drawing;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
using System.Windows;
using System.Windows.Media;
using Point = System.Windows.Point;
namespace Thesis
{
    public class FlowCalculator
    {
        #region params and returning
        private Dictionary<String, List<Point>> graphicsData;
        private PointCollection pointsCollection;
        private FlowCalculatorParams flowCalculatorParamsData;
        private FlowCalculatorResponseData flowCalculatorResponseData;
        #endregion

        #region subvariables
        public static double gravity = 9.81d;
        public static double kexit = 1d;
        #endregion

        public FlowCalculatorResponseData calculateData(FlowCalculatorParams
            flowCalculatorParams)
        {
            flowCalculatorResponseData = new FlowCalculatorResponseData();
            flowCalculatorParamsData = flowCalculatorParams;
            graphicsData = getDataForGraphic();
            #region Gelen verilerle polygonları oluşturacak
            Dictionary<String, PointCollection> points = new Dictionary<String, PointCollection>();
            points.Add("flowProfile", new PointCollection());
        }
    }
}
```

```

points.Add("culvert",newPointCollection());
points.Add("roadSection",newPointCollection());
points.Add("ycProfile",newPointCollection());
points.Add("ynProfile",newPointCollection());
points.Add("hwSection",newPointCollection());
points.Add("twProfile",newPointCollection());
foreach(StringkeyingraphicsData.Keys)
{
foreach(PointpointingraphicsData[key])
{
PointpointNew=newPoint((point.X),(point.Y));
points[key].Add(pointNew);
}
}
#endregion
flowCalclaterResponseData.graphic=points;
flowCalclaterResponseData.q=flowCalclaterParams.q;
flowCalclaterResponseData.tw=flowCalclaterParams.tw;
flowCalclaterResponseData.flowCalclaterParams=flowCalclaterPara
ms;
returnflowCalclaterResponseData;
}
privateDictionary<String,List<Point>>getDataForGraphic()
{
Dictionary<String,List<Point>>data=newDictionary<string,List<Point
>>();
doublehw=0;
PercentFullnessModelpercentFullnessModel=getPercentFullnes(flowCa1
culaterParamsData.sectionType);
doubleyc=10d;
doubletetaC=0;
doubleac=0;
doublepc=0;
doublerc=0;
doubleuc=0;
doubletc=0d;

```

```

doubleRange=0.01d;
doublevalue=0.00001d;
doubleqSon=percentFullnessModel.isError?percentFullnessModel.pipem
axCapacity:flowCalclaterParamsData.q;
if(percentFullnessModel.inletOutletType=="OUTLET")
{
if(percentFullnessModel.inletOutletType=="OUTLET"&&flowCalclaterP
aramsData.sectionType=="circ")
{
while(true)
{
tetaC=getTeta(yc);
ac=(Math.Pow(flowCalclaterParamsData.d,2d)/8d)*(tetaC-
Math.Sin(tetaC));
pc=(flowCalclaterParamsData.d/2d)*tetaC;
rc=ac/pc;
uc=(8*qSon)/(Math.Pow(flowCalclaterParamsData.d,2)*(tetaC-
Math.Sin(tetaC)));
tc=flowCalclaterParamsData.d*Math.Sin(tetaC/2);
doublefirstVal=Math.Pow(flowCalclaterParamsData.q,2d)/gravity;
doublesecondVal=Math.Pow(ac,3)/tc;
if(Math.Abs(firstVal-secondVal)<Range)
{
break;
}
doubler=ac/pc;
doubleqEnd=(1/flowCalclaterParamsData.n)*ac*(Math.Pow(r,(2d/3d)))
*Math.Sqrt(flowCalclaterParamsData.so);
yc=yc-value;
}
}
elseif(percentFullnessModel.inletOutletType=="OUTLET"&&flowCalcula
terParamsData.sectionType=="rect")
{
//tw<yc
yc=Math.Pow((Math.Pow((flowCalclaterParamsData.q/flowCalclaterPa
ramsData.b),2d))/gravity,1d/3d);
ac=yc*flowCalclaterParamsData.b;

```

```

pc=flowCalculatorParamsData.b+2d*yc;
/*rc=ac/pc;
uc=flowCalculatorParamsData.q/ac;*/
}
varbendingValue=0d;
if(flowCalculatorParamsData.bending)
{
bendingValue=getBendingValue();
}
if(percentFullnessModel.pipeMaxCapacity>flowCalculatorParamsData.q)
{
doubletempR=0;
doubletempArea=0;
doubletempT=0;
//partialoutlet
IcDsmDataocOutletDsmPageFivePartial=getPageFiveOutlet(yc,percentFullnessModel);
IcDsmDataocOutletDsmPageFivePartialForHw=getPageFiveOutlet(yc,percentFullnessModel);
doubleycLastPageFive=ocOutletDsmPageFivePartialForHw.ycValues.Last();
doubletetaForHw=(Math.Asin((ycLastPageFive-(flowCalculatorParamsData.d/2d))/(flowCalculatorParamsData.d/2d)))*
(2d))+Math.PI;
doubleareaForHw=0;
if(flowCalculatorParamsData.sectionType=="circ")
{
areaForHw=(Math.Pow(flowCalculatorParamsData.d,2d)/8)*(tetaForHw-Math.Sin(tetaForHw));
hw=((flowCalculatorParamsData.getKentValue()+
kexit+
bendingValue)*(Math.Pow(flowCalculatorParamsData.q,2)/((Math.Pow(areaForHw,2)*2d*gravity))))+
ycLastPageFive+flowCalculatorParamsData.die+flowCalculatorParamsData.l*flowCalculatorParamsData.so;
}
else
{

```

```

areaForHw=ycLastPageFive*flowCalculatorParamsData.b;
hw=((flowCalculatorParamsData.getKentValue()+
kexit+
bendingValue)*(Math.Pow(flowCalculatorParamsData.q,2)/((Math.Pow(a
reaForHw,2)*2d*gravity))))+
ycLastPageFive+flowCalculatorParamsData.die+flowCalculatorParamsDa
ta.l*flowCalculatorParamsData.so;
}
}
else
{
doubletempR=0;
doubletempArea=0;
doubletempT=0;
//fulloutlet
if(flowCalculatorParamsData.sectionType=="rect")
{
tempR=percentFullnessModel.rGeneralRectangle;
tempArea=percentFullnessModel.areaGeneralRectangle;
}
elseif(flowCalculatorParamsData.sectionType=="circ")
{
tempR=percentFullnessModel.rGeneralCircle;
tempArea=percentFullnessModel.areaGeneralCircle;
}
if((flowCalculatorParamsData.die+(flowCalculatorParamsData.d+yc)/2
)>(flowCalculatorParamsData.tw+flowCalculatorParamsData.die))
{
tempT=(flowCalculatorParamsData.die+(flowCalculatorParamsData.d+yc
)/2);
}
else
{
tempT=flowCalculatorParamsData.die+flowCalculatorParamsData.tw;
}
hw=(flowCalculatorParamsData.getKentValue()+kexit+bendingValue+((2
d*gravity*Math.Pow(flowCalculatorParamsData.n,2d)*flowCalculatorPa

```

```

ramsData.1)/Math.Pow(tempR,4d/3d)))*(Math.Pow(flowCalcuLaterParams
Data.q,2d)/(2d*gravity*Math.Pow(tempArea,2d)))+tempT;
}
}
elseif(percentFullnessModel.inletOutletType=="INLET")
{
if(flowCalcuLaterParamsData.sectionType=="circ")
{
while(true)
{
tetaC=getTeta(yc);
ac=(Math.Pow(flowCalcuLaterParamsData.d,2d)/8d)*(tetaC-
Math.Sin(tetaC));
pc=(flowCalcuLaterParamsData.d/2d)*tetaC;
rc=ac/pc;
uc=(8*qSon)/(Math.Pow(flowCalcuLaterParamsData.d,2)*(tetaC-
Math.Sin(tetaC)));
tc=flowCalcuLaterParamsData.d*Math.Sin(tetaC/2);
doublefirstVal=Math.Pow(flowCalcuLaterParamsData.q,2d)/gravity;
doublesecondVal=Math.Pow(ac,3)/tc;
if((firstVal-secondVal)>-hassasiyetRange&&(firstVal-
secondVal)<hassasiyetRange)
{
break;
}
doubler=ac/pc;
doubleeqEnd=(1/flowCalcuLaterParamsData.n)*ac*(Math.Pow(r,(2d/3d)))
*Math.Sqrt(flowCalcuLaterParamsData.so);
yc=yc-Value;
}
}
elseif(flowCalcuLaterParamsData.sectionType=="rect")
{
yc=Math.Pow((Math.Pow((qSon/flowCalcuLaterParamsData.b),2d))/gravi
ty,1d/3d);
ac=yc*flowCalcuLaterParamsData.b;
uc=qSon/ac;
}
}

```

```

vargeneralArea=0d;
varsubmergencyControl=0d;
if(flowCalcuaterParamsData.sectionType=="rect")
{
generalArea=percentFullnessModel.areaGeneralRectangle;
submergencyControl=flowCalcuaterParamsData.q/(Math.Sqrt((gravity*
flowCalcuaterParamsData.h))*generalArea);
}
elseif(flowCalcuaterParamsData.sectionType=="circ")
{
generalArea=percentFullnessModel.areaGeneralCircle;
submergencyControl=flowCalcuaterParamsData.q/(Math.Sqrt((gravity*
flowCalcuaterParamsData.d))*generalArea);
}
varinletKI=0d;
varinletMI=0d;
varunSubmerchW=0d;
varsubmerchW=0d;
vartransition=0d;
varcI=0d;
varyI=0d;
katsayilarInnetTypekatsayilarInnetType=getKatsayilarInnetType();
inletKI=katsayilarInnetType.kI;
inletMI=katsayilarInnetType.mI;
cI=katsayilarInnetType.cI;
yI=katsayilarInnetType.yI;
if(submergencyControl<0.62d)
{
if(flowCalcuaterParamsData.sectionType=="circ")
{
unSubmerchW=((yc/flowCalcuaterParamsData.d)+
(Math.Pow(uc,2d)/(2d*gravity*flowCalcuaterParamsData.d))+
(inletKI*(Math.Pow((flowCalcuaterParamsData.q/(generalArea*Math.S
qrt(flowCalcuaterParamsData.d*gravity))),inletMI)))+
((-
0.5d)*flowCalcuaterParamsData.so))*flowCalcuaterParamsData.d)+fl
owCalcuaterParamsData.die+(flowCalcuaterParamsData.l*flowCalcula
terParamsData.so);

```

```

hw=unSubmercHw;
}else
{
unSubmercHw=((yc/flowCalcuaterParamsData.h)+
(Math.Pow(uc,2d)/(2d*gravity*flowCalcuaterParamsData.h))+
(inletKI*(Math.Pow((flowCalcuaterParamsData.q/(generalArea*Math.S
qrt(flowCalcuaterParamsData.h*gravity))),inletMI)))+
((-
0.5d)*flowCalcuaterParamsData.so))*flowCalcuaterParamsData.h)+fl
owCalcuaterParamsData.die+(flowCalcuaterParamsData.l*flowCalcula
terParamsData.so);
hw=unSubmercHw;
}
}
elseif(submergencyControl>=0.62d&&submergencyControl<=0.70d)
{
if(flowCalcuaterParamsData.sectionType=="circ")
{
unSubmercHw=((yc/flowCalcuaterParamsData.d)+
(Math.Pow(uc,2d)/(2d*gravity*flowCalcuaterParamsData.d))+
(inletKI*(Math.Pow((flowCalcuaterParamsData.q/(generalArea*Math.S
qrt(flowCalcuaterParamsData.d*gravity))),inletMI)))+
((-
0.5d)*flowCalcuaterParamsData.so))*flowCalcuaterParamsData.d)+fl
owCalcuaterParamsData.die+(flowCalcuaterParamsData.l*flowCalcula
terParamsData.so);
submercHw=((cI*
(Math.Pow((flowCalcuaterParamsData.q/(generalArea*Math.Sqrt(flowC
alculaterParamsData.d*gravity))),2))+
yI+(-
0.5d*flowCalcuaterParamsData.so))*flowCalcuaterParamsData.d)+flo
wCalcuaterParamsData.die+(flowCalcuaterParamsData.l*flowCalculat
erParamsData.so);
transition((((submercHw-
unSubmercHw)/flowCalcuaterParamsData.d)/(0.08d))*
(submergencyControl-
0.62d))+((unSubmercHw/flowCalcuaterParamsData.d))*flowCalcuaterPa
ramsData.d)+flowCalcuaterParamsData.die+(flowCalcuaterParamsData
.l*flowCalcuaterParamsData.so);
hw=transition;
}
else

```

```

{
unSubmercHw=((yc/flowCalcuaterParamsData.h)+
(Math.Pow(uc,2d)/(2d*gravity*flowCalcuaterParamsData.h))+
(inletKI*(Math.Pow((flowCalcuaterParamsData.q/(generalArea*Math.S
qrt(flowCalcuaterParamsData.h*gravity))),inletMI)))+
((-
0.5d)*flowCalcuaterParamsData.so))*flowCalcuaterParamsData.h)+flo
wCalcuaterParamsData.die+(flowCalcuaterParamsData.l*flowCalcula
terParamsData.so);
submercHw=((cI*
(Math.Pow((flowCalcuaterParamsData.q/(generalArea*Math.Sqrt(flowc
alculaterParamsData.h*gravity))),2))+
yI+(-
0.5d*flowCalcuaterParamsData.so))*flowCalcuaterParamsData.h)+flo
wCalcuaterParamsData.die+(flowCalcuaterParamsData.l*flowCalculat
erParamsData.so);
transition((((submercHw-
unSubmercHw)/flowCalcuaterParamsData.h)/(0.08d))*(submergencyCont
rol-
0.62d))+((unSubmercHw/flowCalcuaterParamsData.h))*flowCalcuaterPa
ramsData.h)+flowCalcuaterParamsData.die+(flowCalcuaterParamsData
.l*flowCalcuaterParamsData.so);
hw=transition;
}
}
elseif(submergencyControl>0.70d)
{
if(flowCalcuaterParamsData.sectionType=="circ")
{
submercHw=((cI*
(Math.Pow((flowCalcuaterParamsData.q/(generalArea*Math.Sqrt(flowc
alculaterParamsData.d*gravity))),2))+
yI+(-
0.5d*flowCalcuaterParamsData.so))*flowCalcuaterParamsData.d)+flo
wCalcuaterParamsData.die+(flowCalcuaterParamsData.l*flowCalculat
erParamsData.so);
hw=submercHw;
}
else
{
submercHw=((cI*
(Math.Pow((flowCalcuaterParamsData.q/(generalArea*Math.Sqrt(flowc
alculaterParamsData.h*gravity))),2))+

```

```

yI+(-
0.5d*flowCalclaterParamsData.so))*flowCalclaterParamsData.h)+flo
wCalclaterParamsData.die+(flowCalclaterParamsData.l*flowCalclat
erParamsData.so);
hw=submercHW;
}
}
}
IcDsmDataicInletDsmPageOne=null;
IcDsmDataicOutletDsmPageTwo=null;
IcHydraulicJumpDataicHydraulicJumpDataPageThree=null;
IcDsmDataicHydraulicJumpDataPageThreeAddition=null;
IcDsmDataocOutletDsmPageFive=null;
doublepageFiveValue=0d;
#regionInletpageone
if(percentFullnessModel.inletOutletType=="INLET")
{
icInletDsmPageOne=getPageOneInlet(yc,percentFullnessModel,1.01d);
icOutletDsmPageTwo=getPageTwoInlet(percentFullnessModel,1);
icHydraulicJumpDataPageThree=getPageThreeInlet(icInletDsmPageOne,i
cOutletDsmPageTwo);
icHydraulicJumpDataPageThreeAddition=getPageThreeAddition(icInletD
smPageOne,icOutletDsmPageTwo,icHydraulicJumpDataPageThree);
}
elseif(percentFullnessModel.inletOutletType=="OUTLET")
{
if(flowCalclaterParamsData.q>percentFullnessModel.pipeMaxCapacity
&&
flowCalclaterParamsData.tw>flowCalclaterParamsData.d)
{
ocOutletDsmPageFive=newIcDsmData();
ocOutletDsmPageFive.dxSumValues=newList<double>();
ocOutletDsmPageFive.fValues=newList<double>();
ocOutletDsmPageFive.ycValues=newList<double>();
ocOutletDsmPageFive.ykValues=newList<double>();
ocOutletDsmPageFive.ySon=0;
pageFiveValue=0;
}
}

```

```

else
{
ocOutletDsmPageFive=getPageFiveOutlet(yc,percentFullnessModel);
pageFiveValue=getPageFiveOutletOnZeroValue(ocOutletDsmPageFive.ycValues,ocOutletDsmPageFive.dxSumValues);
ocOutletDsmPageFive.ycValues[ocOutletDsmPageFive.ycValues.Count-1]=pageFiveValue;
ocOutletDsmPageFive.dxSumValues[ocOutletDsmPageFive.dxSumValues.Count-1]=0;
}
}
#endregion
doubleculvertHeight=0d;
if(flowCalclaterParamsData.sectionType=="rect")
{
culvertHeight=flowCalclaterParamsData.h;
}
elseif(flowCalclaterParamsData.sectionType=="circ")
{
culvertHeight=flowCalclaterParamsData.d;
}
#region
data.Add("culvert",newList<Point>());
data["culvert"].Add(newPoint(0d,flowCalclaterParamsData.die+
flowCalclaterParamsData.l*flowCalclaterParamsData.so
+culvertHeight));
data["culvert"].Add(newPoint(0d,flowCalclaterParamsData.die+
flowCalclaterParamsData.l*flowCalclaterParamsData.so)
);
data["culvert"].Add(newPoint(flowCalclaterParamsData.l,flowCalclaterParamsData.die)
);
data["culvert"].Add(newPoint(flowCalclaterParamsData.l,flowCalclaterParamsData.die+culvertHeight)
);
data.Add("ycProfile",newList<Point>());
data["ycProfile"].Add(newPoint(0d,yc+flowCalclaterParamsData.die+
flowCalclaterParamsData.l*flowCalclaterParamsData.so));

```

```

data["ycProfile"].Add(newPoint(flowCalculatorParamsData.l,yc+flowCalculatorParamsData.die));
data.Add("ynProfile",newList<Point>());
data["ynProfile"].Add(newPoint(0d,percentFullnessModel.yValue+flowCalculatorParamsData.die+flowCalculatorParamsData.l*flowCalculatorParamsData.so));
data["ynProfile"].Add(newPoint(flowCalculatorParamsData.l,percentFullnessModel.yValue+flowCalculatorParamsData.die));
data.Add("roadSection",newList<Point>());
data["roadSection"].Add(newPoint((flowCalculatorParamsData.l/2d)+(flowCalculatorParamsData.crestLength/2d),flowCalculatorParamsData.crestElevation));
data["roadSection"].Add(newPoint(flowCalculatorParamsData.l,culvertHeight+flowCalculatorParamsData.die));
data["roadSection"].Add(newPoint(0d,flowCalculatorParamsData.die+culvertHeight+(flowCalculatorParamsData.so*flowCalculatorParamsData.l)));
data["roadSection"].Add(newPoint((flowCalculatorParamsData.l/2d)-(flowCalculatorParamsData.crestLength/2d),flowCalculatorParamsData.crestElevation));
data.Add("hwSection",newList<Point>());
doublehwVariable=0d;
if(hw>(culvertHeight+(flowCalculatorParamsData.l*flowCalculatorParamsData.so)+flowCalculatorParamsData.die))
{
hwVariable=((hw-(flowCalculatorParamsData.die+(flowCalculatorParamsData.l*flowCalculatorParamsData.so)+culvertHeight))*((flowCalculatorParamsData.l-flowCalculatorParamsData.crestLength)/2d))/((flowCalculatorParamsData.crestElevation-((flowCalculatorParamsData.die+(flowCalculatorParamsData.l*flowCalculatorParamsData.so)+culvertHeight))));
}
data["hwSection"].Add(newPoint(-25,hw));
data["hwSection"].Add(newPoint(hwVariable,hw));
data.Add("flowProfile",newList<Point>());
List<Point>tableFlowProfile=newList<Point>();
#regionflowProfiletablolarıhesaplanıyor
List<Point>tableOne=newList<Point>();

```

```

List<Point>tableTwo=newList<Point>();
List<Point>tableThree=newList<Point>();
List<Point>tableFour=newList<Point>();
if(percentFullnessModel.inletOutletType=="INLET")
{
if(yc>flowCalculaterParamsData.tw)
{
for(intii=0;ii<icInletDsmPageOne.ykValues.Count;++ii)
{
tableOne.Add(newPoint(icInletDsmPageOne.dxSumValues[ii],icInletDsmPageOne.ykValues[ii]));
}
}
elseif(flowCalculaterParamsData.tw>yc)
{
for(intii=0;ii<icHydraulicJumpDataPageThreeAddition.ykValues.Count;++ii)
{
tableTwo.Add(newPoint(icHydraulicJumpDataPageThreeAddition.dxSumValues[ii],icHydraulicJumpDataPageThreeAddition.ykValues[ii]));
}
tableTwo.Add(newPoint(icHydraulicJumpDataPageThree.intersection.X,icHydraulicJumpDataPageThree.ykIntersection));
tableTwo.Add(newPoint(icHydraulicJumpDataPageThree.intersection.X+icHydraulicJumpDataPageThree.hj,icHydraulicJumpDataPageThree.ykHjTWOussu));
}
}
elseif(percentFullnessModel.inletOutletType=="OUTLET")
{
if(flowCalculaterParamsData.q>percentFullnessModel.pipeMaxCapacity
&&
flowCalculaterParamsData.tw>flowCalculaterParamsData.d)
{
tableFour.Add(newPoint(0d,flowCalculaterParamsData.die+
(flowCalculaterParamsData.l*flowCalculaterParamsData.so)+flowCalculaterParamsData.d));
tableFour.Add(newPoint(flowCalculaterParamsData.l,flowCalculaterParamsData.die+flowCalculaterParamsData.d));
}
}

```

```

}
else
{
for(int ii=0; ii<ocOutletDsmPageFive.ykValues.Count; ++ii)
{
tableThree.Add(newPoint(ocOutletDsmPageFive.dxSumValues[ii], ocOutletDsmPageFive.ykValues[ii]));
}
}
}

tableOne=tableOne.OrderBy(o=>o.X).ToList();
tableTwo=tableTwo.OrderBy(o=>o.X).ToList();
tableThree=tableThree.OrderBy(o=>o.X).ToList();
tableFour=tableFour.OrderBy(o=>o.X).ToList();
tableFlowProfile.AddRange(tableOne);
tableFlowProfile.AddRange(tableTwo);
tableFlowProfile.AddRange(tableThree);
tableFlowProfile.AddRange(tableFour);
data["flowProfile"].AddRange(tableFlowProfile);
#endregion

#region twprofile
data.Add("twProfile", newList<Point>());
double twVariable=0d;
if(flowCalculatorParamsData.tw>(culvertHeight))
{
twVariable=((flowCalculatorParamsData.tw-(culvertHeight))*
(flowCalculatorParamsData.l-
flowCalculatorParamsData.crestLength)/2d
))/((flowCalculatorParamsData.crestElevation-(
culvertHeight));
}

data["twProfile"].Add(newPoint(flowCalculatorParamsData.l+30, flowCalculatorParamsData.tw));
data["twProfile"].Add(newPoint(flowCalculatorParamsData.l-
twVariable, flowCalculatorParamsData.tw));
#endregion

```

```

#endregion
#regionOutletvelocityhesabı
doubleoutletvelocity=0d;
doubleyo=0d;
doubleao=0d;
doubleeqo=0d;
/*if(flowCalculaterParamsData.tw<yc)
{
yo=yc;
}
elseif(flowCalculaterParamsData.tw>yc&&
flowCalculaterParamsData.tw<flowCalculaterParamsData.d)
{
yo=flowCalculaterParamsData.tw;
}
else
{
yo=flowCalculaterParamsData.d;
}*/
List<List<Point>>tablesAll=newList<List<Point>>();
tablesAll.Add(tableOne);
tablesAll.Add(tableTwo);
tablesAll.Add(tableThree);
tablesAll.Add(tableFour);
boolyoFound=false;
tablesAll.ForEach(item=>
{
item.ForEach(itemSub=>
{
if(itemSub.X==flowCalculaterParamsData.l)
{
if(!yoFound)
{
yo=itemSub.Y;
}
}
}
}

```

```

yoFound=true;
}
});
});
qo=(Math.Asin((yo-
(flowCalculatorParamsData.d/2d))/(flowCalculatorParamsData.d/2d))*
2d)+Math.PI;
if(flowCalculatorParamsData.sectionType=="circ")
{
ao=((Math.Pow(flowCalculatorParamsData.d,2d)/8d))*(qo-
Math.Sin(qo));
}
else
{
ao=yo*flowCalculatorParamsData.b;
}
outletVelocity=flowCalculatorParamsData.q/ao;
#endregion
#regionLengthfull
List<Point>fullTablo=newList<Point>();
doublefullLength=0d;
doublefreeLength=0d;
if(tableOne.Count>0)
{
fullTablo=tableOne;
}
elseif(tableTwo.Count>0)
{
fullTablo=tableTwo;
}
elseif(tableThree.Count>0)
{
fullTablo=tableThree;
}
elseif(tableFour.Count>0)
{

```

```

fullTablo=tableFour;
}
if(percentFullnessModel.inletOutletType=="INLET")
{
if(yc<flowCalclaterParamsData.tw)
{
freeLength=ichHydraulicJumpDataPageThree.intersection.X;
fullLength=flowCalclaterParamsData.l-
ichHydraulicJumpDataPageThree.intersection.X-
ichHydraulicJumpDataPageThree.hj;
}else
{
fullTablo.ForEach(item=>
{
if(item.Y==flowCalclaterParamsData.d)
{
if(fullLength==0)
{
fullLength=flowCalclaterParamsData.l-item.X;
freeLength=item.X;
}
}
});
if(freeLength==0)
{
freeLength=flowCalclaterParamsData.l;
}
}
elseif(percentFullnessModel.inletOutletType=="OUTLET")
{
fullTablo.ForEach(item=>
{
if(percentFullnessModel.isError)
{

```

```

fullLength=flowCalculatorParamsData.l;
freeLength=0d;
}
else
{
if(item.Y==flowCalculatorParamsData.d)
{
if(fullLength==0)
{
fullLength=item.X;
freeLength=flowCalculatorParamsData.l-item.X;
}
}
}
});
if(freeLength==0)
{
freeLength=flowCalculatorParamsData.l;
}
}
#endregion
flowCalculatorResponseData.hw=hw;
flowCalculatorResponseData.flowType=percentFullnessModel.inletOutletType;
flowCalculatorResponseData.yc=yc;
flowCalculatorResponseData.yValue=percentFullnessModel.yValue;
flowCalculatorResponseData.outletVelocity=outletVelocity;
flowCalculatorResponseData.lengthFull=fullLength;
flowCalculatorResponseData.lengthFree=freeLength;
flowCalculatorResponseData.yo=yo;
flowCalculatorResponseData.tables=newList<List<Point>>();
flowCalculatorResponseData.tables.Add(tableOne);
flowCalculatorResponseData.tables.Add(tableTwo);
flowCalculatorResponseData.tables.Add(tableThree);
flowCalculatorResponseData.tables.Add(tableFour);

```

```

flowCalculatorResponseData.ocOutletDsmPageFive=ocOutletDsmPageFive
;
flowCalculatorResponseData.icHydraulicJumpDataPageThree=icHydraulicJumpDataPageThree;
flowCalculatorResponseData.icHydraulicJumpDataPageThreeAddition=icHydraulicJumpDataPageThreeAddition;
flowCalculatorResponseData.icInletDsmPageOne=icInletDsmPageOne;
flowCalculatorResponseData.icOutletDsmPageTwo=icOutletDsmPageTwo;
returndata;
}
publicdoubleRoundUp(doubleinput,intplaces)
{
doublemultiplier=Math.Pow(10,Convert.ToDouble(places));
doubledonen=Math.Ceiling(input*multiplier)/multiplier;
returndonen;
}
publicICDsmDatagetPageOneInlet(doubleyc,PercentFullnessModelpercentFullness,doublenumber)
{
ICDsmDataicInletDsmPageOne=newICDsmData();
doubledeltaY=0.01d;
doubleycSon=yc;
doubleySon=percentFullness.yValue*number;
doubleea=0d;
doublep=0d;
doubler=0d;
doubleu=0d;
doubleteta=0d;
doublet=0d;
doublefr=0d;
doubleesf=0d;
doublefrAv=0d;
doubleesfAv=0d;
doubleedx=0d;
doubleedxSum=0d;
doubleedxSon=0d;
doublef1=0d;

```

```

double yUssu=0d;
int indis=0;
double lastFrOne=0d;
double lastFrTwo=0d;
double lastSfOne=0d;
double lastSfTwo=0d;
double yk=0;
List<double> ycValues=new List<double>();
List<double> dxSumValues=new List<double>();
List<double> f1Values=new List<double>();
List<double> ykValues=new List<double>();
/*ycValues.Add(ycSon);
f1Values.Add(f1);
ykValues.Add(yk);*/
while(true)
{
    if(flowCalculatorParamsData.sectionType=="rect")
    {
        a=ycSon*flowCalculatorParamsData.b;
        p=2d*ycSon+flowCalculatorParamsData.b;
        r=a/p;
        u=flowCalculatorParamsData.q/a;
        fr=u/(Math.Sqrt(gravity*ycSon));
    }
    elseif(flowCalculatorParamsData.sectionType=="circ")
    {
        teta=getTeta(ycSon);
        t=(2d*flowCalculatorParamsData.d/2d)*(Math.Sin(teta/2));
        a=circleArea(teta);
        p=(flowCalculatorParamsData.d/2)*teta;
        r=a/p;
        u=flowCalculatorParamsData.q/a;
        fr=u/(Math.Sqrt(gravity*(a/t)));
    }
    sf=Math.Pow((u*flowCalculatorParamsData.n)/(Math.Pow(r,2d/3d)),2);
}

```

```

if(indis%2==0)
{
lastFrOne=fr;
}
else
{
lastFrTwo=fr;
}
if(indis%2==0)
{
lastSfOne=sf;
}
else
{
lastSfTwo=sf;
}
if(lastFrTwo!=0&&lastSfTwo!=0)
{
frAv=(lastFrOne+lastFrTwo)/2d;//soniki frdeğerinin ortalaması
sfAv=(lastSfOne+lastSfTwo)/2d;//soniki sfdeğerinin ortalaması
dx=Math.Abs(((deltaY*(1d-
Math.Pow(frAv,2d))))/(flowCalclaterParamsData.so-sfAv));
dxSum=dxSum+dx;
}
if(flowCalclaterParamsData.sectionType=="rect")
{
yUssu=ycSon/2;
f1=(yUssu*a)+((Math.Pow(flowCalclaterParamsData.q,2d)/(gravity*a)
));
}
elseif(flowCalclaterParamsData.sectionType=="circ")
{
yUssu=((Math.Pow(flowCalclaterParamsData.d,3d)/24)*
((3d*Math.Sin(teta/2d))-
(Math.Pow(Math.Sin(teta/2d),3d))-
(3d*(teta/2d))*(Math.Cos(teta/2d)))/a;

```

```

f1=(yUssu*a)+((Math.Pow(flowCalcuLaterParamsData.q,2d)/(gravity*a)
));
}
yk=ycSon+
(flowCalcuLaterParamsData.die+(flowCalcuLaterParamsData.l*flowCalc
uLaterParamsData.so))-
(flowCalcuLaterParamsData.so*dxSum);
if((ycSon<ySon||dxSum>flowCalcuLaterParamsData.l)
{
if((ycSon)<ySon)
{
ycSon=ySon;
}
elseif(dxSum>flowCalcuLaterParamsData.l)
{
dxSum=flowCalcuLaterParamsData.l;
ycSon=percentFullness.yValue;
}
ycValues.Add(ycSon);
dxSumValues.Add(dxSum);
f1Values.Add(f1);
ykValues.Add(yk);
++indis;
break;
}
else
{
ycValues.Add(ycSon);
dxSumValues.Add(dxSum);
f1Values.Add(f1);
ykValues.Add(yk);
ycSon=(ycSon-deltaY);
if(ycSon<(percentFullness.yValue*1.01d))
{
deltaY=(percentFullness.yValue*1.01d)-ycSon;

```

```

}
++indis;
}
}
yk=ycSon+
(flowCalculaterParamsData.die+(flowCalculaterParamsData.l*flowCalc
ulaterParamsData.so))-
(flowCalculaterParamsData.so*flowCalculaterParamsData.l);
f1Values.Add(f1);
dxSumValues.Add(flowCalculaterParamsData.l);
ykValues.Add(yk);
ycValues.Add(percentFullness.yValue);
icInletDsmPageOne.ykValues=ykValues;
icInletDsmPageOne.ySon=ySon;
icInletDsmPageOne.ycValues=ycValues;
icInletDsmPageOne.fValues=f1Values;
icInletDsmPageOne.dxSumValues=dxSumValues;
return icInletDsmPageOne;
}
public IcDsmData getPageTwoInlet(PercentFullnessModel percentFullness
,doublenumber)
{
IcDsmData icInletDsmPageOne=new IcDsmData();
double deltaY=0.01d;
double ycSon=flowCalculaterParamsData.tw;
double ySon=percentFullness.yValue*number;
double ea=0d;
double ep=0d;
double er=0d;
double eu=0d;
double teta=0d;
double t=0d;
double fr=0d;
double sf=0d;
double frAv=0d;
double sfAv=0d;

```

```

double dx=0d;
double dxSum=0d;
double dxSon=0d;
double f1=0d;
double yUssu=0d;
int indis=0;
double lastFrOne=0d;
double lastFrTwo=0d;
double lastSfOne=0d;
double lastSfTwo=0d;
double yk=0;
List<double> ycValues=new List<double>();
List<double> dxSumValues=new List<double>();
List<double> f1Values=new List<double>();
List<double> ykValues=new List<double>();
/*ycValues.Add(ycSon);
f1Values.Add(f1);
ykValues.Add(yk);*/
double dh=0d;
if(flowCalculatorParamsData.sectionType=="rect")
{
dh=flowCalculatorParamsData.h;
}
elseif(flowCalculatorParamsData.sectionType=="circ")
{
dh=flowCalculatorParamsData.d;
}
if(flowCalculatorParamsData.tw>dh)
{
ycSon=dh;
}
else
{
ycSon=flowCalculatorParamsData.tw;
}

```

```

while(true)
{
if(flowCalclaterParamsData.sectionType=="rect")
{
a=ycSon*flowCalclaterParamsData.b;
p=2d*ycSon+flowCalclaterParamsData.b;
r=a/p;
u=flowCalclaterParamsData.q/a;
fr=u/(Math.Sqrt(gravity*ycSon));
}
elseif(flowCalclaterParamsData.sectionType=="circ")
{
teta=getTeta(ycSon);
t=(2d*flowCalclaterParamsData.d/2d)*(Math.Sin(teta/2));
a=circleArea(teta);
p=(flowCalclaterParamsData.d/2)*teta;
r=a/p;
u=flowCalclaterParamsData.q/a;
fr=u/(Math.Sqrt(gravity*(a/t)));
}
sf=Math.Pow((u*flowCalclaterParamsData.n)/(Math.Pow(r,2d/3d)),2);
if(indis%2==0)
{
lastFrOne=fr;
}
else
{
lastFrTwo=fr;
}
if(indis%2==0)
{
lastSfOne=sf;
}
else
{

```

```

lastSfTwo=sf;
}
if(indis==0)
{
dxSon=flowCalcuLaterParamsData.l;
}
if(lastFrTwo!=0&&lastSfTwo!=0)
{
frAv=(lastFrOne+lastFrTwo)/2d;
sfAv=(lastSfOne+lastSfTwo)/2d;
if(flowCalcuLaterParamsData.tw>dh)
{
doubledeltaY=0d;
doubledx=0d;
deltaYeni=flowCalcuLaterParamsData.tw-dh;
dx=Math.Abs((((deltaY*(1d-
Math.Pow(frAv,2d))))/(flowCalcuLaterParamsData.so-sfAv)));
dxSum=dxSum+dx;
dx=Math.Abs((((deltaYeni*(1d-
Math.Pow(frAv,2d))))/(flowCalcuLaterParamsData.so-sfAv)));
if(indis==0)
{
dxSon=flowCalcuLaterParamsData.l;
}
elseif(indis==1)
{
dxSon=flowCalcuLaterParamsData.l-dx;
}
else
{
dxSon=flowCalcuLaterParamsData.l-dx-dxSum;
}
}
else
{

```

```

dx=Math.Abs((((deltaY*(1d-
Math.Pow(frAv,2d))))/(flowCalcuaterParamsData.so-sfAv)));
dxSum=dxSum+dx;
dxSon=flowCalcuaterParamsData.l-dxSum;
}
}
if(flowCalcuaterParamsData.sectionType=="rect")
{
yUssu=ycSon/2;
f1=(yUssu*a)+((Math.Pow(flowCalcuaterParamsData.q,2d)/(gravity*a)
));
}
elseif(flowCalcuaterParamsData.sectionType=="circ")
{
yUssu=((Math.Pow(flowCalcuaterParamsData.d,3d)/24)*
((3d*Math.Sin(teta/2d))-
(Math.Pow(Math.Sin(teta/2d),3d))-
(3d*(teta/2d))*(Math.Cos(teta/2d)))/a;
f1=(yUssu*a)+((Math.Pow(flowCalcuaterParamsData.q,2d)/(gravity*a)
));
}
yk=ycSon+
(flowCalcuaterParamsData.die+(flowCalcuaterParamsData.l*flowCalc
uaterParamsData.so))-
(flowCalcuaterParamsData.so*dxSon);
if((ycSon)<ySon)
{
ycSon=ySon;
ycValues.Add(ycSon);
if(indis==0)
{
dxSumValues.Add(flowCalcuaterParamsData.l);
}
else
{
dxSumValues.Add(dxSon);
}
}

```

```

f1Values.Add(f1);
ykValues.Add(yk);
++indis;
break;
}
else
{
ycValues.Add(ycSon);
dxSumValues.Add(dxSon);
f1Values.Add(f1);
ykValues.Add(yk);
if(flowCalclaterParamsData.tw>dh)
{
if(indis==0||indis==1)
{
ycSon=dh;
}
else
{
ycSon=ycSon-deltaY;
}
}
else
{
ycSon=(ycSon-deltaY);
}
++indis;
}
}
icInletDsmPageOne.ykValues=ykValues;
icInletDsmPageOne.ySon=ySon;
icInletDsmPageOne.ycValues=ycValues;
icInletDsmPageOne.fValues=f1Values;
icInletDsmPageOne.dxSumValues=dxSumValues;
return icInletDsmPageOne;

```

```

}
private IchHydraulicJumpData getPageThreeInlet(IcDsmData dataOne, IcDsm
Data dataTwo)
{
LineIntersection lineIntersection = new LineIntersection();
IchHydraulicJumpData ichHydraulicJumpData = new IchHydraulicJumpData();
int indisFoundOne = -1;
int indisFoundTwo = -1;
PointF intersection = new PointF();
PointF close_p1 = new PointF();
PointF close_p2 = new PointF();
bool lines_intersect = false;
bool segments_intersect = false;
PointF intersectionTemp = new PointF();
for (var i = 0; i < dataOne.fValues.Count - 1; ++i)
{
double fTemp = dataOne.fValues[i];
double dxTemp = dataOne.dxSumValues[i];
double fTempNext = dataOne.fValues[i + 1];
double dxTempNext = dataOne.dxSumValues[i + 1];
for (var i2 = 0; i2 < dataTwo.fValues.Count - 1; ++i2)
{
double f2Temp = dataTwo.fValues[i2];
double dx2Temp = dataTwo.dxSumValues[i2];
double f2TempNext = dataTwo.fValues[i2 + 1];
double dx2TempNext = dataTwo.dxSumValues[i2 + 1];
lineIntersection.FindIntersection(new System.Drawing.PointF((float)
dxTemp, (float) fTemp),
new System.Drawing.PointF((float) dxTempNext, (float) fTempNext),
new System.Drawing.PointF((float) dx2Temp, (float) f2Temp),
new System.Drawing.PointF((float) dx2TempNext, (float) f2TempNext),
outlines_intersect,
outsegments_intersect,
outintersection,
outclose_p1,
outclose_p2

```

```

);
if(segments_intersect)
{
if(intersection.X>intersectionTemp.X){
indisFoundOne=i;
indisFoundTwo=i2;
intersectionTemp.X=intersection.X;
intersectionTemp.Y=intersection.Y;
}
//gotofinish;
}
}
intersection=intersectionTemp;
//finish:
if(indisFoundOne!=-1&&indisFoundTwo!=-1)
{
iCHydraulicJumpData.isIntersection=true;
doubledxOne=dataOne.dxSumValues[indisFoundOne];
doubledxTwo=dataOne.dxSumValues[indisFoundOne+1];
doubleycOne=dataOne.ycValues[indisFoundOne];
doubleycTwo=dataOne.ycValues[indisFoundOne+1];
doubledxOnePageTwo=dataTwo.dxSumValues[indisFoundTwo];
doubledxTwoPageTwo=dataTwo.dxSumValues[indisFoundTwo+1];
doubleycOnePageTwo=dataTwo.ycValues[indisFoundTwo];
doubleycTwoPageTwo=dataTwo.ycValues[indisFoundTwo+1];
doubleyhjOne1=(double)intersection.X-(double)dxOne;
doubleyhjOne2=ycTwo-ycOne;
doubleyhjOne3=dxTwo-dxOne;
doubleyhjOne=((yhjOne1*yhjOne2)/yhjOne3)+ycOne;
doubleyhjTwo1=(double)intersection.X-(double)dxOnePageTwo;
doubleyhjTwo2=ycTwoPageTwo-ycOnePageTwo;
doubleyhjTwo3=dxTwoPageTwo-dxOnePageTwo;
doubleyhjTwo=((yhjTwo1*yhjTwo2)/yhjTwo3)+ycOnePageTwo;
doublehj=0d;

```

```

double yhjTwoUssu=0d;
if(flowCalclaterParamsData.sectionType=="circ")
{
    hj=6d*(yhjTwo);
    double yhjTwoUssu1=(double)intersection.X+hj-(double)dxOnePageTwo;
    double yhjTwoUssu2=ycTwoPageTwo-ycOnePageTwo;
    double yhjTwoUssu3=dxTwoPageTwo-dxOnePageTwo;
    yhjTwoUssu=((yhjTwoUssu1*yhjTwoUssu2)/yhjTwoUssu3)+ycOnePageTwo;
}
elseif(flowCalclaterParamsData.sectionType=="rect")
{
    double aHj=(yhjOne*flowCalclaterParamsData.b);
    double uHj=flowCalclaterParamsData.q/aHj;
    double frHj=uHj/Math.Sqrt(gravity*yhjOne);
    hj=220*yhjOne*Math.Tanh((frHj-1)/22);
    double yhjTwoUssu1=((double)intersection.X+hj)-
    ((double)dxOnePageTwo);
    double yhjTwoUssu2=(ycTwoPageTwo-ycOnePageTwo);
    double yhjTwoUssu3=dxTwoPageTwo-dxOnePageTwo;
    yhjTwoUssu=((yhjTwoUssu1*yhjTwoUssu2)/yhjTwoUssu3)+ycOnePageTwo;
}
double ykIntersection=0d;
double ykHjTwoUssu=0d;
ykIntersection=((flowCalclaterParamsData.die+
(flowCalclaterParamsData.l*flowCalclaterParamsData.so))-
(((double)intersection.X)*flowCalclaterParamsData.so))+yhjOne;
ykHjTwoUssu=yhjTwoUssu+(flowCalclaterParamsData.die+
(flowCalclaterParamsData.l*flowCalclaterParamsData.so))-
(((double)intersection.X+hj)*flowCalclaterParamsData.so);
ichHydraulicJumpData.hj=hj;
ichHydraulicJumpData.intersection=intersection;
ichHydraulicJumpData.yhjTwoUssu=yhjTwoUssu;
ichHydraulicJumpData.ykIntersection=ykIntersection;
ichHydraulicJumpData.ykHjTwoUssu=ykHjTwoUssu;
ichHydraulicJumpData.yhjOne=yhjOne;

```

```

}
else
{
    icHydraulicJumpData.isIntersection=false;
}
return icHydraulicJumpData;
}

private IcDsmData getPageThreeAddition(IcDsmData dataOne, IcDsmData dataTwo, IcHydraulicJumpData dataThreeGelen)
{
    var dataThree = dataThreeGelen;
    IcDsmData icHydraulicJumpData = new IcDsmData();
    icHydraulicJumpData.dxSumValues = newList<double>();
    icHydraulicJumpData.ykValues = newList<double>();
    double differenceOne = Double.MaxValue;
    int minIndisOne = 0;
    double differenceTwo = Double.MaxValue;
    int minIndisTwo = 0;
    for (var i = 0; i < dataOne.ycValues.Count - 1; ++i)
    {
        double differenceOneTemp = Math.Abs(dataOne.ycValues[i] - dataThree.yhjOne);
        if (differenceOneTemp <= differenceOne)
        {
            differenceOne = differenceOneTemp;
            minIndisOne = i;
        }
    }
    for (var i = 0; i < dataTwo.ycValues.Count - 1; ++i)
    {
        double differenceTwoTemp = Math.Abs(dataTwo.ycValues[i] - dataThree.yhjTwoUssu);
        if (differenceTwoTemp <= differenceTwo)
        {
            differenceTwo = differenceTwoTemp;
            minIndisTwo = i;
        }
    }
}

```

```

    }
    }
    for(var i=0; i<dataOne.ycValues.Count-1; ++i)
    {
        if(i>minIndisOne)
        {
            break;
        }
        else
        {
            ichHydraulicJumpData.ykValues.Add(dataOne.ykValues[i]);
            ichHydraulicJumpData.dxSumValues.Add(dataOne.dxSumValues[i]);
        }
    }
    for(var i=0; i<dataTwo.ycValues.Count-1; ++i)
    {
        if(i>minIndisTwo)
        {
            break;
        }
        else
        {
            ichHydraulicJumpData.ykValues.Add(dataTwo.ykValues[i]);
            ichHydraulicJumpData.dxSumValues.Add(dataTwo.dxSumValues[i]);
        }
    }
    return ichHydraulicJumpData;
}

public double getPageFiveOutletOnZeroValue(List<double> ycValues, List<double> dxSumValues)
{
    double y0=0d;
    double y1=ycValues[ycValues.Count-2];
    double y2=ycValues[ycValues.Count-1];
    double x1=dxSumValues[dxSumValues.Count-2];

```

```

double x2 = dxSumValues[dxSumValues.Count-1];
y0 = y1 - (((y1 - y2) / (x1 - x2)) * x1);
return y0;
}

public IcDsmData getPageFiveOutlet(double yc, PercentFullnessModel percentFullness)
{
    IcDsmData icOutletDsmPageOne = new IcDsmData();
    double deltaY = 0.015d;
    double ycSon = yc > flowCalculatorParamsData.tw ? yc : flowCalculatorParamsData.tw;
    double ea = 0d;
    double ep = 0d;
    double er = 0d;
    double eu = 0d;
    double teta = 0d;
    double t = 0d;
    double efr = 0d;
    double sf = 0d;
    double efrAv = 0d;
    double sfAv = 0d;
    double dx = 0d;
    double dxSum = 0d;
    double dxSon = 0d;
    int indis = 0;
    double lastFrOne = 0d;
    double lastFrTwo = 0d;
    double lastSfOne = 0d;
    double lastSfTwo = 0d;
    double yk = 0;
    List<double> ycValues = new List<double>();
    List<double> dxSumValues = new List<double>();
    List<double> ykValues = new List<double>();
    dxSum = flowCalculatorParamsData.l;
    int iterationStopForY = 0;
    while(true)

```

```

{
if(flowCalclaterParamsData.sectionType=="rect")
{
a=ycSon*flowCalclaterParamsData.b;
p=2d*ycSon+flowCalclaterParamsData.b;
r=a/p;
u=flowCalclaterParamsData.q/a;
fr=u/(Math.Sqrt(gravity*ycSon));
}
elseif(flowCalclaterParamsData.sectionType=="circ")
{
teta=getTeta(ycSon);
t=(2d*flowCalclaterParamsData.d/2d)*(Math.Sin(teta/2));
a=circleArea(teta);
p=(flowCalclaterParamsData.d/2)*teta;
r=a/p;
u=flowCalclaterParamsData.q/a;
fr=u/(Math.Sqrt(gravity*(a/t)));
}
sf=Math.Pow((u*flowCalclaterParamsData.n)/(Math.Pow(r,2d/3d)),2);
if(indis%2==0)
{
lastFrOne=fr;
}
else
{
lastFrTwo=fr;
}
if(indis%2==0)
{
lastSfOne=sf;
}
else
{
lastSfTwo=sf;
}

```

```

}
if(lastFrTwo!=0&&lastSfTwo!=0)
{
frAv=(lastFrOne+lastFrTwo)/2d;
sfAv=(lastSfOne+lastSfTwo)/2d;
dx=Math.Abs(((deltaY*(1d-
Math.Pow(frAv,2d))))/(flowCalcuaterParamsData.so-sfAv));
dxSum=dxSum-dx;
}
yk=ycSon+
(flowCalcuaterParamsData.die+(flowCalcuaterParamsData.l*flowCalc
uaterParamsData.so))-
(flowCalcuaterParamsData.so*dxSum);
if(dxSum<0)
{
dxSum=0;
//break;
}
if(iterationStopForY!=2)
{
ycValues.Add(ycSon);
}
dxSumValues.Add(dxSum);
ykValues.Add(yk);
if(dxSum==0)
{
break;
}
if(iterationStopForY!=2)
{
ycSon=ycSon+deltaY;
if(ycSon>percentFullness.yValue)
{
ycSon=percentFullness.yValue;
}
}
}

```

```

++indis;
if(iterationStopForY==1)
{
iterationStopForY=2;
}
elseif(iterationStopForY==0)
{
if(ycSon==percentFullness.yValue)
{
iterationStopForY=1;
}
}
}
icOutletDsmPageOne.dxSumValues=dxSumValues;
icOutletDsmPageOne.ycValues=ycValues;
icOutletDsmPageOne.ykValues=ykValues;
return icOutletDsmPageOne;
}
private KatsayilarInnetType getKatsayilarInnetType()
{
KatsayilarInnetType katsayilarInnetType = new KatsayilarInnetType();
if(flowCalculaterParamsData.inletType=="ir1")
{
katsayilarInnetType.kI=0.1475d;
katsayilarInnetType.mI=1d;
katsayilarInnetType.cI=1.1173d;
katsayilarInnetType.yI=0.81d;
}
elseif(flowCalculaterParamsData.inletType=="ic1")
{
katsayilarInnetType.kI=0.3155d;
katsayilarInnetType.mI=2d;
katsayilarInnetType.cI=1.2816d;
katsayilarInnetType.yI=0.67d;
}
}

```

```

elseif(flowCalclaterParamsData.inletType=="ic2")
{
katsayilarInnetType.kI=0.2512d;
katsayilarInnetType.mI=2d;
katsayilarInnetType.cI=0.9402d;
katsayilarInnetType.yI=0.74d;
}
elseif(flowCalclaterParamsData.inletType=="ic3")
{
katsayilarInnetType.kI=0.1449d;
katsayilarInnetType.mI=2d;
katsayilarInnetType.cI=1.0207d;
katsayilarInnetType.yI=0.69d;
}
returnkatsayilarInnetType;
}
privatedoublegetBendingValue()
{
doublevalue=0;
if(flowCalclaterParamsData.radiusOfBend=="bir"&&flowCalclaterParamsData.angleOfBend=="doksan")
{
value=0.5d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="bir"&&flowCalclaterParamsData.angleOfBend=="kirkbes")
{
value=0.37d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="bir"&&flowCalclaterParamsData.angleOfBend=="yirmiikibucuk")
{
value=0.25d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="iki"&&flowCalclaterParamsData.angleOfBend=="doksan")
{

```

```

value=0.3d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="iki"&&flowCalclate
rParamsData.angleOfBend=="kirkbes")
{
value=0.22d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="iki"&&flowCalclate
rParamsData.angleOfBend=="yirmiikibucuk")
{
value=0.15d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="dort"&&flowCalclat
erParamsData.angleOfBend=="doksan")
{
value=0.25d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="dort"&&flowCalclat
erParamsData.angleOfBend=="kirkbes")
{
value=0.19d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="dort"&&flowCalclat
erParamsData.angleOfBend=="yirmiikibucuk")
{
value=0.12d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="alti"&&flowCalclat
erParamsData.angleOfBend=="doksan")
{
value=0.15d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="alti"&&flowCalclat
erParamsData.angleOfBend=="kirkbes")
{
value=0.11d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="alti"&&flowCalclat
erParamsData.angleOfBend=="yirmiikibucuk")

```

```

{
value=0.08d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="sekiz"&&flowCalcula
terParamsData.angleOfBend=="doksan")
{
value=0.15d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="sekiz"&&flowCalcula
terParamsData.angleOfBend=="kirkbes")
{
value=0.11d;
}
elseif(flowCalclaterParamsData.radiusOfBend=="sekiz"&&flowCalcula
terParamsData.angleOfBend=="yirmiikibucuk")
{
value=0.08d;
}
returnvalue;
}
publicPercentFullnessModelgetPercentFullnes(StringsectionType)
{
PercentFullnessModelpercentFullnessModel=newPercentFullnessModel()
;
doubley=1d;
doubleqEnd=0;
doubleareaGeneralRect=0d;
doublepGeneralRect=0d;
doublelGeneralRect=0d;
doubleareaGeneralCircle=0d;
doublepGeneralCircle=0d;
doublelGeneralCircle=0d;
doublepipeMaxCapacity=0d;
if(sectionType=="rect")
{
areaGeneralRect=flowCalclaterParamsData.b*flowCalclaterParamsDat
a.h;

```

```

pGeneralRect=flowCalculatorParamsData.b+2*flowCalculatorParamsData
.h;
rGeneralRect=areaGeneralRect/pGeneralRect;
pipeMaxCapacity=(1/flowCalculatorParamsData.n)*areaGeneralRect*Math
h.Pow(rGeneralRect,2d/3d)*Math.Sqrt(flowCalculatorParamsData.so);
}
elseif(sectionType=="circ")
{
areaGeneralCircle=Math.PI*Math.Pow(flowCalculatorParamsData.d,2)/4
;
pGeneralCircle=Math.PI*flowCalculatorParamsData.d;
rGeneralCircle=areaGeneralCircle/pGeneralCircle;
pipeMaxCapacity=(1/flowCalculatorParamsData.n)*areaGeneralCircle*M
ath.Pow(rGeneralCircle,2d/3d)*Math.Sqrt(flowCalculatorParamsData.s
o);
}
percentFullnessModel.areaGeneralCircle=areaGeneralCircle;
percentFullnessModel.areaGeneralRectangle=areaGeneralRect;
percentFullnessModel.rGeneralCircle=rGeneralCircle;
percentFullnessModel.rGeneralRectangle=rGeneralRect;
percentFullnessModel.pipeMaxCapacity=pipeMaxCapacity;
if(flowCalculatorParamsData.q>pipeMaxCapacity&&flowCalculatorParam
sData.so<0.01)
{
percentFullnessModel.isError=true;
percentFullnessModel.percentFullness=1;
percentFullnessModel.inletOutletType="OUTLET";
percentFullnessModel.yValue=flowCalculatorParamsData.d;
returnpercentFullnessModel;
}
doublearea=0;
doublep=0;
while(!(Math.Abs(flowCalculatorParamsData.q-qEnd)<0.01d))
{
area=0;
p=0;
if(sectionType=="rect")
{

```

```

area=flowCalculatorParamsData.b*y;
p=2*y+flowCalculatorParamsData.b;
}
elseif(sectionType=="circ")
{
doubleteta=getTeta(y);
area=circleArea(teta);
p=(flowCalculatorParamsData.d/2)*teta;
}
doubler=area/p;
qEnd=(1/flowCalculatorParamsData.n)*area*(Math.Pow(r,(2d/3d)))*Math.Sqrt(flowCalculatorParamsData.so);
if(qEnd>flowCalculatorParamsData.q)
{
y=y-0.0001d;
}
elseif(qEnd<flowCalculatorParamsData.q)
{
y=y+0.0001d;
}
}
doublepercentFullness=0;
doublesCurve=0d;
if(sectionType=="rect")
{
percentFullness=y/flowCalculatorParamsData.h;
sCurve=(flowCalculatorParamsData.so*
(Math.Pow(flowCalculatorParamsData.h,1d/3d)))/
Math.Pow(flowCalculatorParamsData.n,2);
}
elseif(sectionType=="circ")
{
percentFullness=y/flowCalculatorParamsData.d;
sCurve=(flowCalculatorParamsData.so*
(Math.Pow(flowCalculatorParamsData.d,1d/3d)))/

```

```

Math.Pow(flowCalculatorParamsData.n,2);
}
List<double>sCurveY=sCurveFunction(sCurve);
StringinletOutletDurum="";
if(sCurveY.Count==0)
{
inletOutletDurum="OUTLET";
}
elseif(sCurveY.Count==1)
{
if(percentFullness<=sCurveY[0])
{
inletOutletDurum="INLET";
}
else
{
inletOutletDurum="OUTLET";
}
}
elseif(sCurveY.Count==2)
{
if(percentFullness<=sCurveY[1]&&percentFullness>=sCurveY[0])
{
inletOutletDurum="INLET";
}
else
{
inletOutletDurum="OUTLET";
}
}
percentFullnessModel.inletOutletType=inletOutletDurum;
percentFullnessModel.percentFullness=percentFullness;
percentFullnessModel.sCurve=sCurve;
percentFullnessModel.sCurveY=sCurveY;
percentFullnessModel.yValue=y;

```

```

returnpercentFullnessModel;
}
private double circleArea(double input)
{
return(Math.Pow(flowCalculatorParamsData.d/2d,2)/2d)*(input-
Math.Sin(input));
}
private List<double> sCurveFunction(double input)
{
List<double> y=new List<double>();
double k1=0;
double k2=0;
double k3=0;
double k4=0;
double k5=0;
double k6=0;
double k7=0;
if(input<52.27d&&input>23)
{
k1=(double)Decimal.Parse("9.39174500148327E-
09",System.Globalization.NumberStyles.Float);
k2=(double)Decimal.Parse("-2.220425679186E-
06",System.Globalization.NumberStyles.Float);
k3=(double)Decimal.Parse("2.16668542181467E-
04",System.Globalization.NumberStyles.Float);
k4=(double)Decimal.Parse("-1.11752092470707E-
02",System.Globalization.NumberStyles.Float);
k5=(double)Decimal.Parse("3.21690426436267E-
01",System.Globalization.NumberStyles.Float);
k6=(double)Decimal.Parse("-
4.91133718844596E+00",System.Globalization.NumberStyles.Float);
k7=(double)Decimal.Parse("3.12222696144422E+01",System.Globalizati
on.NumberStyles.Float);
y.Add((k1*Math.Pow(input,6))+
(k2*Math.Pow(input,5))+
(k3*Math.Pow(input,4))+
(k4*Math.Pow(input,3))+
(k5*Math.Pow(input,2))+
(k6*Math.Pow(input,1))+

```

```

(k7));
}
if(input>22.35818d&&input<=23)
{
k1=(double)Decimal.Parse("-2.68325750417396E-
05",System.Globalization.NumberStyles.Float);
k2=(double)Decimal.Parse("1.46794739323830E-
03",System.Globalization.NumberStyles.Float);
k3=(double)Decimal.Parse("2.09146519123563E-
02",System.Globalization.NumberStyles.Float);
k4=(double)Decimal.Parse("0",System.Globalization.NumberStyles.Flo
at);
k5=(double)Decimal.Parse("0",System.Globalization.NumberStyles.Flo
at);
k6=(double)Decimal.Parse("0",System.Globalization.NumberStyles.Flo
at);
k7=(double)Decimal.Parse("3.76949341842621E+02",System.Globalizati
on.NumberStyles.Float);
y.Add((k1*Math.Pow(input,6))+
(k2*Math.Pow(input,5))+
(k3*Math.Pow(input,4))+
(k4*Math.Pow(input,3))+
(k5*Math.Pow(input,2))+
(k6*Math.Pow(input,1))+
(k7));
k1=(double)Decimal.Parse("3.29794472660797E-
05",System.Globalization.NumberStyles.Float);
k2=(double)Decimal.Parse("-1.79988866066003E-
03",System.Globalization.NumberStyles.Float);
k3=(double)Decimal.Parse("2.55828830258070E-
02",System.Globalization.NumberStyles.Float);
k4=(double)Decimal.Parse("0",System.Globalization.NumberStyles.Flo
at);
k5=(double)Decimal.Parse("0",System.Globalization.NumberStyles.Flo
at);
k6=(double)Decimal.Parse("0",System.Globalization.NumberStyles.Flo
at);
k7=(double)Decimal.Parse("-
4.56161830462374E+02",System.Globalization.NumberStyles.Float);
y.Add((k1*Math.Pow(input,6))+
(k2*Math.Pow(input,5))+

```

```

(k3*Math.Pow(input,4))+
(k4*Math.Pow(input,3))+
(k5*Math.Pow(input,2))+
(k6*Math.Pow(input,1))+
(k7));
}
if(input<27.2&&input>23)
{
k1=(double)Decimal.Parse("3.88166374803578E-
06",System.Globalization.NumberStyles.Float);
k2=(double)Decimal.Parse("-4.78508567382523E-
04",System.Globalization.NumberStyles.Float);
k3=(double)Decimal.Parse("2.30495976514921E-
02",System.Globalization.NumberStyles.Float);
k4=(double)Decimal.Parse("-5.266476273560E-
01",System.Globalization.NumberStyles.Float);
k5=(double)Decimal.Parse("5.08105147132512E-
00",System.Globalization.NumberStyles.Float);
k6=(double)Decimal.Parse("0",System.Globalization.NumberStyles.Flo
at);
k7=(double)Decimal.Parse("-
2.24749482201971E+02",System.Globalization.NumberStyles.Float);
y.Add((k1*Math.Pow(input,6))+
(k2*Math.Pow(input,5))+
(k3*Math.Pow(input,4))+
(k4*Math.Pow(input,3))+
(k5*Math.Pow(input,2))+
(k6*Math.Pow(input,1))+
(k7));
}
if(input<52.27&&input>=27.2)
{
k1=(double)Decimal.Parse("-1.71023073435318E-
09",System.Globalization.NumberStyles.Float);
k2=(double)Decimal.Parse("4.26932071568475E-
07",System.Globalization.NumberStyles.Float);
k3=(double)Decimal.Parse("-4.45239215174444E-
05",System.Globalization.NumberStyles.Float);
k4=(double)Decimal.Parse("2.49182844589486E-
03",System.Globalization.NumberStyles.Float);

```

```

k5=(double)Decimal.Parse("-7.94531234277731E-
02",System.Globalization.NumberStyles.Float);
k6=(double)Decimal.Parse("1.38814741811886E-
00",System.Globalization.NumberStyles.Float);
k7=(double)Decimal.Parse("-9.81253103282846E-
00",System.Globalization.NumberStyles.Float);
y.Add((k1*Math.Pow(input,6))+
(k2*Math.Pow(input,5))+
(k3*Math.Pow(input,4))+
(k4*Math.Pow(input,3))+
(k5*Math.Pow(input,2))+
(k6*Math.Pow(input,1))+
(k7));
}
if(input>=52.27)
{
k1=(double)Decimal.Parse("-6.45495839140220E-
14",System.Globalization.NumberStyles.Float);
k2=(double)Decimal.Parse("5.83563716856533E-
11",System.Globalization.NumberStyles.Float);
k3=(double)Decimal.Parse("-2.16576156260535E-
08",System.Globalization.NumberStyles.Float);
k4=(double)Decimal.Parse("4.24897114574786E-
06",System.Globalization.NumberStyles.Float);
k5=(double)Decimal.Parse("-4.70875527839830E-
04",System.Globalization.NumberStyles.Float);
k6=(double)Decimal.Parse("2.87716729991395E-
02",System.Globalization.NumberStyles.Float);
k7=(double)Decimal.Parse("1.85970791857319E-
01",System.Globalization.NumberStyles.Float);
y.Add((k1*Math.Pow(input,6))+
(k2*Math.Pow(input,5))+
(k3*Math.Pow(input,4))+
(k4*Math.Pow(input,3))+
(k5*Math.Pow(input,2))+
(k6*Math.Pow(input,1))+
(k7));
}
return y;

```

```

}
privatedoublegetTeta(doubley)
{
doubleteta=0;
//teta=2*Math.Acos((1-(y/flowCalclaterParamsData.d/2)));
teta=(Math.Asin((y-
(flowCalclaterParamsData.d/2d))/(flowCalclaterParamsData.d/2d))*
2d)+Math.PI;
returnteta;
}
publicclassIcDsmData
{
publicdoubleySon{get;set;}
publicList<double>ycValues{get;set;}
publicList<double>dxSumValues{get;set;}
publicList<double>fValues{get;set;}
publicList<double>ykValues{get;set;}
}
publicclassIcHydraulicJumpData
{
publicbooleanIntersection{get;set;}
publicdoublehj{get;set;}
publicPointFintersection{get;set;}
publicdoubleyhjTwoUssu{get;set;}
publicdoubleykIntersection{get;set;}
publicdoubleykhjTwoUssu{get;set;}
publicdoubleyhjOne{get;set;}
}
publicclassPercentFullnessModel
{
publicStringinletOutletType{get;set;}
publicdoublepercentFullness{get;set;}
publicdoubleCurve{get;set;}
publicList<double>sCurveY{get;set;}
publicbooleanError{get;set;}
publicdoubleareaGeneralCircle{get;set;}
}

```

```

public double areaGeneralRectangle { get; set; }
public double rGeneralCircle { get; set; }
public double lGeneralRectangle { get; set; }
public double yValue { get; set; }
public double pipeMaxCapacity { get; set; }
}

public class KatsayilarInnetType
{
    public double kI { get; set; }
    public double mI { get; set; }
    public double cI { get; set; }
    public double yI { get; set; }
}

public class FlowCalculatorResponseData
{
    public Dictionary<String, PointCollection> graphic { get; set; }
    public double q { get; set; }
    public double hw { get; set; }
    public String flowType { get; set; }
    public double yc { get; set; }
    public double yValue { get; set; }
    public double tw { get; set; }
    public double outletVelocity { get; set; }
    public double lengthFull { get; set; }
    public double lengthFree { get; set; }
    public double yo { get; set; }
    public List<List<Point>> tables { get; set; }
    public FlowCalculatorParams flowCalculatorParams { get; set; }
    public ICdsmData icInletDsmPageOne { get; set; }
    public ICdsmData icOutletDsmPageTwo { get; set; }
    public IC HydraulicJumpData icHydraulicJumpDataPageThree { get; set; }
    public ICdsmData icHydraulicJumpDataPageThreeAddition { get; set; }
    public ICdsmData ocOutletDsmPageFive { get; set; }
}
}

```

```

}
using System;
using System.Collections.Generic;
using System.Linq;
using System.Text;
using System.Threading.Tasks;
namespace Thesis
{
    public class FlowCalculatorParams
    {
        public string sectionType { get; set; }
        public string inletType { get; set; }
        public double q { get; set; }
        public double d { get; set; }
        public double b { get; set; }
        public double h { get; set; }
        public double so { get; set; }
        public double n { get; set; }
        public double tw { get; set; }
        public double die { get; set; }
        public double l { get; set; }
        public bool bending { get; set; }
        public string radiusOfBend { get; set; }
        public string angleOfBend { get; set; }
        public double crestLength { get; set; }
        public double crestElevation { get; set; }
        public double q { get; set; }
        public double getKentValue()
        {
            double kent = 0d;
            if (inletType == "ic1")
            {
                kent = 0.5d;
            }
            else

```

```
{  
  kent=0.2d;  
}  
return kent;  
}
```

