Espirales
Revista multidisciplinaria de investigación científica

Development of a specific software for the calculation of open channels with uniform flow considering energy principles

Desarrollo de un software específico para el cálculo de canales abiertos de flujo uniforme considerando los principios de energía

Liliana Lizbeth López López*
María Fernanda Pico Núñez*
Bernarda Estefanía Abril Gavilanes*

Received: July 13, 2023
Approved: September 22, 2023

Cite this:

López, L., Pico, M., Abril, B., (2023). Desarrollo de un software específico para el cálculo de canales abiertos de flujo uniforme considerando los principios de energía. Espirales Revista Multidisciplinaria de investigación científica, 7 (47),

Magister en Ingeniería Civil Mención Estructuras Metálicas, Universidad Técnica de Ambato, ll.lopez@uta.edu.ec, https://orcid.org/0009-0004-7730-3162

Magister en Ingeniería Civil Mención Estructuras Metálicas, Universidad Técnica de Ambato, mf.pico@uta.edu.ec, https://orcid.org/0000-0002-8468-3026

Magister en Ingeniería Civil Mención Estructuras Metálicas, Gobierno Autónomo Descentralizado Municipal de Ambato, eprilab@hotmail.com, https://orcid.org/0000-0003-0788-0824

Abstract

The purpose of this research project is the codification of a specific software for the calculation of open channels of uniform flow considering the energy principles, which allows to obtain quickly and safely the normal and critical tie, geometric elements, flow rate, optimal hydraulic section of the sections proposed by Ven Te Chow, rectangular, trapezoidal, triangular, circular, parabolic, rectangular with rounded corners and triangular with rounded bottom, in addition to the geometric elements for any equation of the parabola, the hydraulic headroom and weirs. To verify the veracity of the developed program "SN CANALES v2.0", the results obtained were checked with the existing HCANALES software and manually; obtaining a margin of error of less than 1.5%, thus verifying that the values obtained by the software are reliable.

Keywords: Software, Open channels, Uniform flow.

Resumen

El presente proyecto de investigación tiene como propósito la codificación de un software específico para el cálculo de canales abiertos de flujo uniforme considerando los principios de energía, el cual permite obtener de manera rápida y segura el tirante normal, tirante crítico, elementos geométricos, caudal, sección hidráulica óptima de las secciones planteadas por Ven Te Chow, rectangular, trapezoidal, triangular, circular, parabólica, rectangular con esquinas redondeadas y triangular con fondo redondeado, además los elementos geométricos para cualquier ecuación de la parábola, el resalto hidráulico y vertederos. Para comprobar la veracidad del programa desarrollado "SN CANALES v2.0", los resultados obtenidos fueron comprobados con el software existente HCANALES y mediante la forma manual; obteniendo un margen de error menor al 1.5%, con lo que se pudo verificar que los valores obtenidos por el software son confiables.

Palabras clave: Software, Canales abiertos, Flujo uniforme.

Introduction

Water is a substance of vital importance for human beings, so there has been a need to quantify and efficiently use water resources for human consumption, industry, agriculture, energy regeneration, etc., due to this, human beings have always been in search of how to measure it (Barragán Mendoza et al., 2007).

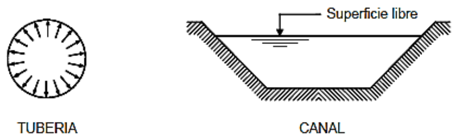
At the beginning of the application of knowledge on hydraulic engineering, there were no technological tools like the current ones and therefore a lot of time was spent in the process of performing mathematical calculations or in turn in the design of a structure, since tables or nomograms were used. This repetitive process could unintentionally cause errors (Acosta Lozada & Naranjo Bustos, 2016).

At present, there are softwares that allow the calculation of open channels, but not all the sections proposed by Ven Te Chow are available, so the need arose to develop a software where all these sections are available in order to contribute to the reduction of the calculation time and to provide reliability in the results.

Thus, the project is composed of two approaches: theoretical and practical. Within the theoretical approach, important issues in canal hydraulics are addressed and as for the practical approach, the development of a specific software for the calculation of open canals in which the energy principles are considered.

Based on the research, it can be mentioned that the flow of water in a conduit can be open channel flow or pipe flow. These two types of flow are very similar, but they differ in the fact that open channel flow must have a free surface and pipe flow does not (Barragán Mendoza et al., 2007).

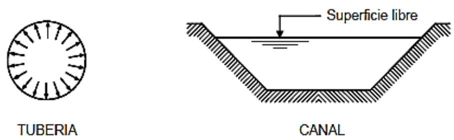
Figure 1. Difference between pipes and channels.



A. Open Channels

An open channel is defined as one that does not completely enclose a liquid stream between solid boundaries and is therefore in direct contact with the atmosphere.

Figure 2. Open channels.



B. Geometry of a Channel

A natural channel is generally very irregular in shape and varies from place to place, from approximately a parabola to approximately a trapezoid. Artificial channels are designed with regular geometric shapes, a channel constructed with an invariable cross section and a constant bottom slope is known as a prismatic channel. The term section of a channel refers to the cross section taken perpendicular to the direction of flow (Rodriguez Ruiz, 2008).

The most common cross sections are:

Trapezoidal section: Used in earth channels because they provide the necessary slopes for stability, and in lined channels.

Rectangular section: Because the rectangle has vertical sides, it is generally used for canals built with stable materials, wooden aqueducts, for canals excavated in rock and for lined canals.

Triangular section: Used for lined ditches on highways, also in small earth channels, mainly for ease of layout. They are also used as lined road culverts.

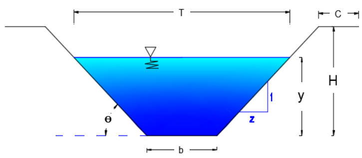
Parabolic section: This is sometimes used for lined channels and is the approximate shape of many natural and old earth channels.

Circular section: The circle is the most common section for small and medium size sewers and culverts.

C. Geometric elements of a section

Geometric elements are the properties of the section of a channel that can be defined by the geometry of the section and the depth of flow. These elements are very important for flow calculation.

Figure 3. Detail of the geometric elements of the cross section of a channel.



1. *Flow depth:* The vertical distance from the lowest point of a channel section to the free surface, i.e. the maximum depth of water in the channel. This term is often interchanged with the flow depth of the section (D).
2. *Surface width or water mirror "T":* The width of the free surface of the water, in meters.
3. *Wetted area "A":* The wetted area (A) is the cross-sectional area of the flow perpendicular to the flow direction.
4. *Wetted Perimeter "P":* The wetted perimeter (P) is the length of the line of the intersection of the wetted channel surface and a transverse plane perpendicular to the direction of flow.

D. Geometric elements of a parabolic channel

To calculate the geometric elements of a parabolic channel based on the equation of the parabola, it is necessary to know the general equation of a parabola.

General equation of the parabola:

$$fx = ax^2 + bx + c \quad (1)$$

E. Flow Classification

The classification of flow in open channels is summarized as:

A) ***Permanent flow***

1) Permanent uniform flow
2) Permanent varied flow
- Gradually varied flow
- Rapidly varying flow

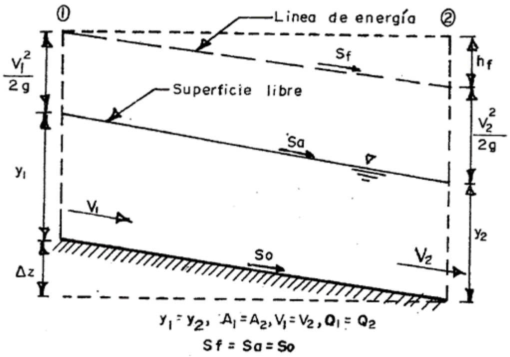
B) *Non-permanent flow*

1) Uniform unsteady flow
2) Non-steady flow
- Gradually varied non-permanent flow
- Rapidly varying non-permanent flow.

- Uniform Flow in Open Channels

Uniform flow occurs when the mean velocity is constant over any part of the channel section.

Figure 4. Uniform flow



In uniform flow the slope of the friction energy line (Sf), the slope of the free surface of the water (Sa) and the geometric slope of the channel (So) are equal. If the mean velocity remains constant, it has to do with the fact that the flow has a constant velocity at each point of the cross section along the channel, that is, the velocity distribution of each section does not alter.(Acosta Lozada & Naranjo Bustos, 2016).

Uniform flow is an ideal state that is difficult to achieve, however, in most cases (especially in straight and long channels of constant cross section and bottom slope) (Sotelo, 1887).

G. Manning's Roughness Coefficient

The value of n (Manning's roughness coefficient) is variable and depends on several factors. The factors that have the greatest influence on the Manning's roughness coefficient in either artificial or natural channels are:

1) Surface roughness.
2) Vegetation.
3) Irregularity of the channel.
4) Channel alignment.
5) Sedimentation.
6) Scour.
7) Obstruction.
8) Channel size and shape.

H. Uniform Flow Calculation

In a channel the volumetric flow is calculated by the continuity equation:

Q=A*V (2)

Where:

Q= Flow rate

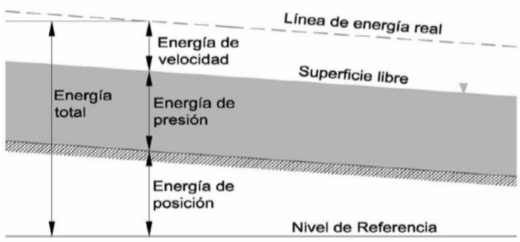
V= Flow velocity

A= Area

I. Energy

Energy is the capacity required to do work. Work is the result of applying a force along a certain path and is usually defined as the product of a force times the length of the path in the direction of application. Energy and work are expressed in the same units, i.e. kpm or N m.

Figure 5. Energy in a channel



J. Specific Energy

The specific energy is therefore the sum of the flow and the velocity load. The bottom of the channel will change each time it rises or falls, in short the specific energy depends on the water flow.

The following equation is used to determine the specific energy:

$$E = y + \frac{v^2}{2g} \qquad (3)$$

K. Critical Flow

If the critical state of flow exists along the entire length of the channel or along a section of the channel, the flow in the channel is a critical flow. The channel slope that maintains a given flow at a uniform, critical depth is known as the critical slope (Sc). A channel slope less than the critical slope will produce a slower flow of a subcritical nature for the given flow and is therefore known as a gentle or subcritical slope. A slope greater than the critical slope will produce a faster flow of a supercritical nature and is known as a steep or supercritical slope.

1. Critical Flow Conditions

- Specific energy is minimum for a given flow rate
- The flow rate is maximum for a given specific energy.
- The specific strength is minimum for a given flow rate.
- The velocity head is equal to half the hydraulic depth in a low slope channel.
- The Froude number is equal to unity.
- The flow velocity in a low-slope channel with uniform velocity distribution is equal to the celerity of small gravity waves in shallow water caused by local disturbances.

Critical Flow Determination

For a critical flow state to occur, the condition must be met in which the Froude number is equal to one, under this flow state, the specific energy is minimal for a given flow rate and the current is unstable and subject to fluctuations in the depth of the liquid. (Barragán Mendoza et al., 2007).

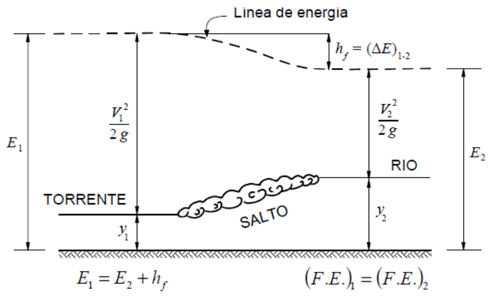
The following equation is used to determine the critical flow:

$$\frac{Q^2}{gA^3}T = 1 \qquad (4)$$

L. Hydraulic Highlight

The hydraulic jump is defined as the abrupt elevation of the liquid surface, when the permanent runoff passes from the supercritical to the subcritical regime. It is a local phenomenon very useful for dissipating hydraulic energy. This abrupt change of regime is characterized by a rapid change in the curvature of the flow paths, which produces vortices (turbulence) on the horizontal axis, including the appearance of velocities in the opposite direction to the flow that cause collisions between particles in a more or less chaotic manner, resulting in a large dissipation of energy.

Figure 6. Hydraulic Resalt



M. Types of Hydraulic Resalt

The hydraulic headwater can be classified according to the Froude number of the flow upstream of the jump.

- For Froude number F=1,

The flow is critical, and no jump is formed here.

- For a Froude number F>1 and F<1.7

The surface of the water shows ripples and a jump called undulatory jump occurs.

- For a Froude number F>1.7 and F<2.5

We have a weak jump. This is characterized by the formation of a series of eddies on the jump surface, but the water surface downstream remains uniform (Rodríguez Ruiz, 2008).

- For a Froude number F>2.5 and F<4.5

An oscillating jump occurs.

- For Froude number F>4.5 and F<8.0

A permanent or stable jump occurs

- For Froude number F=8.0 and greater

The strong jump is produced.

N. Hydraulic Resalt Calculation

a. Energy Loss

The loss of energy in the shoulder is equal to the difference of the specific energies before and after the shoulder (Rocha Felices, 2017).

Energy loss according to BERNOULLI:

ΔE= E1-E2 (5)

b. Height of the Highlight

The height of the hydraulic jump is defined as the difference between the tie rods after and before the jump.

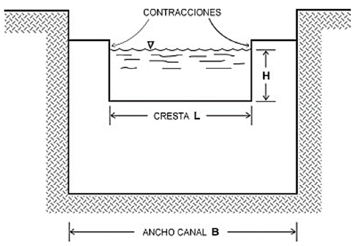
H= Y2-Y1 (6)

O. Landfills

According to Balloffet, a weir is an open contour opening, located in the wall of a reservoir, or in a barrier placed in a channel or river, through which the water contained in the reservoir drains or overflows (Netto et al., 1988).

Weirs are structures formed by placing a thin or thick wall perpendicular to the flow over which runoff occurs. Their operation is based on the theory of rimless orifices for thin-walled weirs and critical flow conditions for thick-walled weirs.

Figure 7. Landfill



Where:

H = Load on the landfill

L = Length of the weir crest

B = Approach channel width

P. Types of Landfills

In the most diverse forms and arrangements, landfills present the most diverse behaviors, with several factors serving as the basis for the present classification (Netto et al., 1988):

1) *By shape*

a) Simple (rectangular, trapezoidal, triangular, etc).

b) Composites (combined sections).

2) *Relative sill height*

a) Complete or free landfills p > p'

b) Incomplete or drowned landfills p < p'

3) *Wall thickness*

a) Thin-walled landfills.

b) Thick wall landfills (e > 0.66 H)

4) *Ridge length*

a) Landfills without lateral contractions (L = B).

b) Contracted landfills (L < B) (with one or two contractions).

Materials and methods

The present project is based on an explanatory research, due to the search of the cause-effect relationship in the calculation of open channels of uniform flow that considers the principles of energy, within a manual process and the use of a software. In addition, it is considered an applied research since the knowledge of channel hydraulics will be put into practice to develop this specific software that will decrease the calculation time for both students and engineers. Then, the data will be taken from three sources: by the manual method that consists of the application of the relevant definitions and equations; by the method with existing software where it will be supported by HCANALES and finally by the software developed SN CANALES v2.0L.

Results

Table 1. *Error percentages obtained in the developed software compared to the manual process and the existing HCANALES software, for different types of sections:*

	SECTION TYPE	ERROR RATE
1	Parabolic section	< 0.1%
2	Rectangular session	0.01% - 1.5%
3	Trapezoidal section	0.01% - 0.6%
4	Triangular session	0.01% - 0.2%
5	Rectangular session with rounded corners	0.01% - 0.4%
6	Triangular session with rounded bottom	0.01% - 0.5%

7	Thin-walled rectangular weir	0.01% - 0.1%
8	Triangular landfill	0.01% - 1.01%
9	Trapezoidal weir	0.01% - 0.1%
10	Circular landfill	0.01% - 0.1%,
11	Submerged landfill	0.01%

After having carried out an analysis of the results obtained by the following methods: manual, with the HCANALES Software and the developed software SN CANALES v2.0L, we obtained an error of less than 1% between the results obtained, giving veracity to the stated hypothesis. Having verified that the developed software has a significant influence on the calculation time of open channels of uniform flow in which the energy principles are considered", it is determined that evidently having a software significantly decreases the time it takes to calculate them, while having more accurate values than when performing a manual calculation because the software uses all the decimals for the calculation.

In the developed software there is the main screen, where we can access the main functions by means of drop-down menus.

From the drop-down menus you have access to the different screens that allow the calculation of the

- Normal brace
- Critical tie rod
- Flow rate
- Geometric elements
- Optimum hydraulic section
- Hydraulic Highlight
- Landfills

In the different calculation screens, the numerical values corresponding to the data necessary to perform the calculations must be entered.

A reference image is incorporated in each calculation screen according to the cross section to be calculated.

The units of the input and output data depend on the system of units chosen for the calculation, for which we have the metric and English system, which must be selected before calculating.

To start the calculation, the "CALCULATE" button must be pressed, there is also a "CLEAR" button which allows the user to clear the input and output data, and a "MAIN MENU" button which allows the user to exit the current window and return to the main screen.

Conclusions

Since water is the vital liquid for human beings, it must be ensured that all people have access to this element and that the means of transportation is adequate.

The results of the calculation of the geometric elements of a parabolic section obtained by manual resolution and those obtained by means of the developed application have an error rate of less than 0.1%, so it is deduced that the use of the software is reliable and valid.

The results of the calculation of the hydraulic head of the different sections proposed by Ven Te Chow, obtained by manual resolution and those obtained by means of the developed application, have an error percentage between 0.01% and 1.5%, and since this is the allowed range, it can be deduced that the use of the software is reliable and valid.

The results of the landfill calculation obtained by means of the developed application have an error percentage between 0.05% and 1%, this range of error is allowed so it is deduced that the use of the software is reliable and valid.

Therefore, the results obtained with the software developed have an error of less than 1% compared to the values obtained with the calculation performed in HCANALES, so the use of this program is valid for the different calculations it presents.

The error that occurs between the results of the manual calculations and those of the software is due to the number of decimal places with which you are working.

References

Acosta Lozada, R., and Naranjo Bustos, C. (2016). *Development of a software for the calculation of uniform flow open channels* (Universidad Técnica de Ambato. Faculty of Civil and Mechanical Engineering. Carrera de Ingeniería Civil ed.). https://repositorio.uta.edu.ec/jspui/handle/123456789/24785

Barragan Mendoza, J., Reyes Carrillo, A., and Acosta Velasquez, L. (2007). *Software for the design of open channels*.

Netto, A., Fernandez, M., De Araujo, R., and Eiji, A. (1988). *MANUAL OF HYDRAULICS* (EDGAR BUCHER ed.). https://www.academia.edu/44471773/MANUAL_de_Hidr%C3%A1ulica

Rocha Felices, A. (2017). *HYDRAULICS OF PIPELINES AND CANALS.*

https://www.academia.edu/36993564/HIDRAULICA_DE_TUBERIAS_Y_CANALES

Rodríguez Ruiz, P. (2008). *CHANNEL HYDRAULICS*.

Soleto, G. (1887). *Flow in a Canal* (Universidad Autónoma de México ed.). Notes on Hydraulics II.