Design of an Open Channel

Name

Course

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Date

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Introduction

Open channels are designed to carry a design discharge in an economical and safe way. The channel is always designed to control floods, where the channel design discharge is done to represent the peak discharge expected to come as a result of the flood events within a specified period and within a given region. At most times, the discharge is always obtained from the hydrological study of the upstream watershed. However, the channels may also be designed for the purpose of irrigation, which is utilized for the distribution of water within the irrigation fields. In such scenarios, the design discharge is determined by considering the total delivery requirements, therefore, open channels are designed for uniform or normal flow conditions.

Generally, designing an open channel will encompass the selection of the channel shape, sizes, and the alignment type of the lining material and longitudinal slope (Ahlmann, J., Canney, & Meier, 2017, p. 9). The design will also be specific in its consideration of several feasible hydraulic designs, which will help in the overall determination of cost effective alternatives. This report is specifically emphasizing the hydraulic consideration involved in channel design rather than the vast economic impact that may affect the overall design.

Numerical analysis

General design considerations

The first step of open channel design involves the selection of the channel alignment. The topography of the area, the existing and planned adjacent structures and transportation facilities, and the available width of the right of way usually determines the alignment of the channel

(Yunianta & Setiadji, 2019, p. 40). The topography is responsible for controlling the invert elevations and the bottom slopes of the channel.

For most cases with man-made surface channels, trapezoidal cross-sections are opted for, though in other scenarios, parabolic, triangular, and rectangular channels may also be used. The main reason for selecting a cross-sectional shape and size is to determine the hydraulic shape and size needed to accommodate the channel design discharge.

Fundamentals of an open channel

Open channels are man-made conveyance structures with open tops that include estuaries, streams, and rivers. A very essential characteristic of an open channel is that it contains an open, free surface at atmospheric pressure. The open channel flow can occur in conduits with closed tops such as culverts and pipes, provided that the conduit is flowing partially (James, 2018, p. 50). Some good examples to illustrate open channels are storm sewers and sanitary sewers that contain free surfaces classified as open flow channels.

Geometric elements of an open channel

A channel's design is always defined by its cross-section, taken perpendicular to the flow direction as provided in the figure, the fundamental elements of the channel are defined as follows (Bennett & Mays., 2017, p. 100) :

i. Flow depth y is defined as the vertical distance from the channel bottom to the free surface;
ii. The depth of flow section is defined as the perpendicular measurement done to the bottom of the channel;

iii. The top width of the channel is defined as the width of the channel section at the free surface;

iv. The wetted perimeter is the length of the interface between the water and the channel boundary;

v. The flow area is the entire cross-section where the flow of liquid takes place;

vi. The hydraulic depth is the flow area divided by the top width $D = A/T$;

vii. The hydraulic radius is the flow area divided by the wetted perimeter $R = A/P$.

The main reason for this report is to develop a realistic plan and design for a drainage channel to ensure that flow velocities and discharge rates are maximized. This report has primarily examined the selection of tools, as well as the method of analysis and design calculations utilizing the use of uniform flow versus gradual flow method. The calculation is shown below, and the collective summary of the flow along the channel, together with graphical representation, has been attached:

$$q = 6.78 \times 3.75 \times 10^{7} \times 8.625 \times 10^{-5} /360$$

$$q = 1.6539 \times 10^{3}\ km/h/360$$

$$q = 0.459 m/h$$

We can calculate the flow rate as follows:

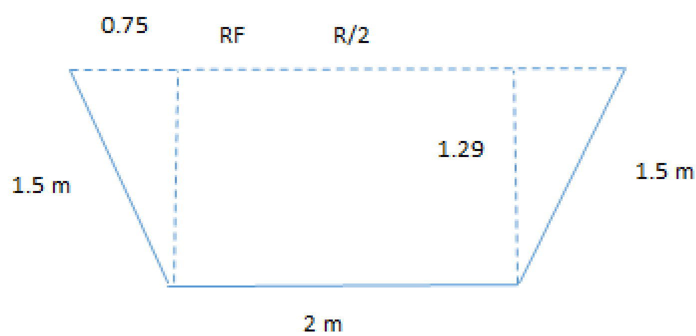
$$Q = \frac{1.49}{h} \times AR^{2/3}\sqrt{5}$$

Assume the type of channel to be designed in trapezoids

Given that

$N = 0.013$

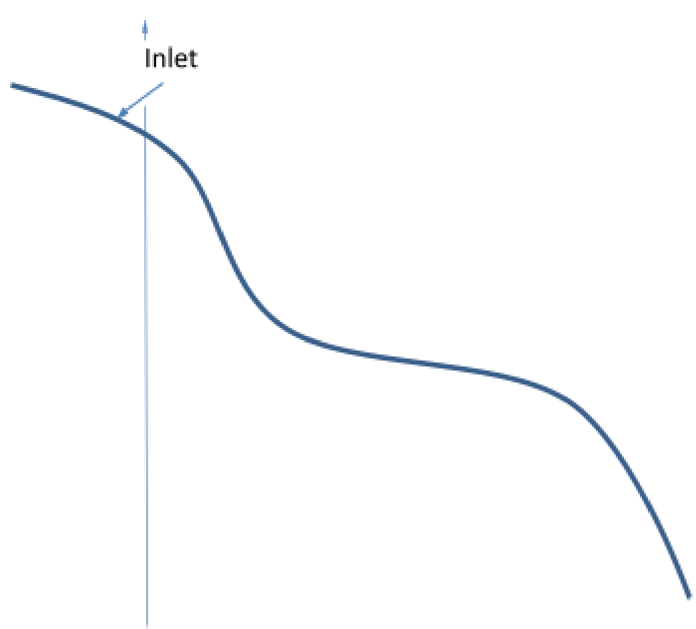
$A = 6.78\ km^2$

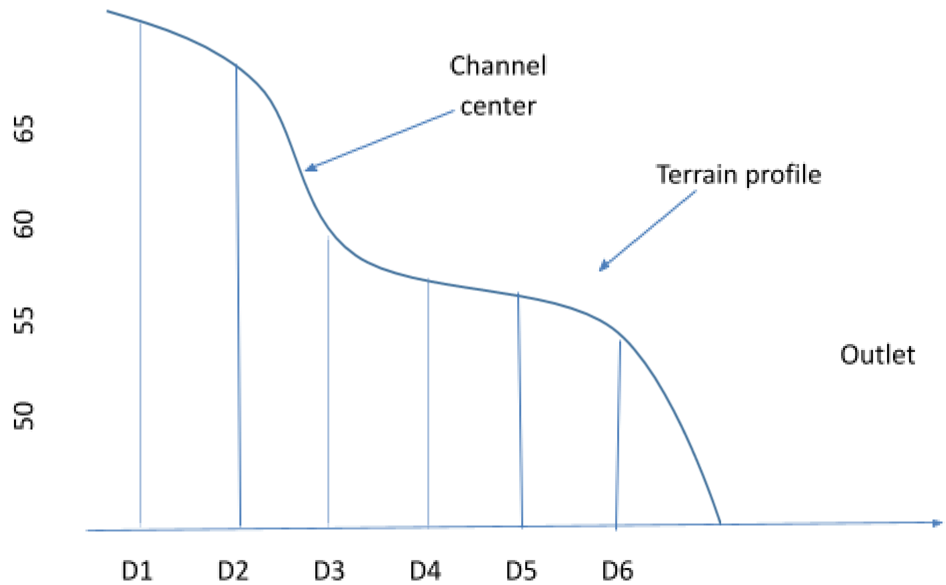


$$Q = \frac{1.49}{0.13} \times 6.78 \times (5 \times 10^3)^{2/3} (\sqrt{0.125})$$

Q= 0.254m^3/s

Longitudinal profile for single flow





$Distance\ between\ contours\ =\ 5m$

$Horizontal\ distance\ =\ 1200m$

$Peak\ =\ 200$

Calculations

$Drop\ height\ =\ (65\ -\ 50)\ =\ 15m$

$Horizontal\ distance\ =\ 1200m$

$Slope\ =\ (15/1200)\ =\ 0.0125$

Rational formula

$Q_p = CIA/360$

Where Q_P = peak flow, $C = dimension\ runoff\ coefficient, I = rainfall\ intensity$

$A = 6.78km$

$C = 0.15\ in/hr\ or\ 0.375cm/hr$

$I = 3.45\ in/hr\ or\ 8.625cm/hr$

Run-off coefficient

From the preliminary design, the geology of the area suited an assumption of group C clay soil, shallow loam soil with a high organic content.

Summary table showing the channel profile

Depth	Flow rate	area	Width	Wetted perimeter	z	energy	n	slope
0.2	$0.254m^3/s$	6.78	2	5	2	2.12	0.013	0.025
0.4	$0.544m^3/s$	6.78	2	5.26	2	2.45	0.013	0.025
0.6	$0.844m^3/s$	6.78	2	5.68	2	2.87	0.013	0.025
0.8	$0.984m^3/s$	6.78	2	6.72	2	3.88	0.013	0.025
1.0	$1.054m^3/s$	6.78	2	7.84	2	4.35	0.013	0.025
1.2	$2.284m^3/s$	6.78	2.4	9.975	2	4.85	0.013	0.025
1.4	$2.864m^3/s$	6.78	2.8	10.25	3	5.69	0.013	0.025

Energy and Momentum Principle

Critical flow

Critical flow is defined as a special type of open channel flow which mainly takes place under specific conditions. The flow is usually a cross-sectional flow type, which is not maintained along the entire length of the channel. The flow may take place at the entrance of a steep channel, at the section where the channel characteristic changes, as well as at the exit of a mild channel. The report emphasizes the important aspects that will help to understand the significance of critical flow. A list of essential conditions associated with critical flow will be provided to supplement the other definitions provided in regards to channel flow (Wang, Chen, X., Chen, & You, 2018, p. 55). Therefore at the critical state of flow, the following conditions are much more considered:

i. The specific energy is at minimum at a given discharge;
ii. The Froude number is equal to 1;
iii. The specific momentum is at maximum for a specific energy;
iv. The discharge is at maximum for a given momentum.

Froude number

Generally, the Froude number is dimensionless and is characterized with the following equation,

$$F_r = \frac{V}{\sqrt{gD}} = \frac{V}{\sqrt{g\left(\frac{A}{T}\right)}} = \frac{Q}{\sqrt{g(\frac{A^3}{T})}}$$

Where c

F_r = Froude number

V= velocity

Q= discharge

G= gravitational acceleration

D= hydraulic depth

A= flow area

T= top width

Generally, the denominator $\sqrt{gD}$ is the speed of the gravity wave in an open channel, also called the wave celerity

Normal flow

This kind of flow is characterized by a constant velocity along the open channel, provided that the flow area, depth, and velocity are constant along the channel cross section. In most given scenarios, normal flow is very common in prismatic channels, and it rarely occurs naturally. Nevertheless, the flows tend to become normal along the channel in the absence of forms of flow control, such as hydraulic structures (Bennett & Mays., 2017).

Flow resistance

The flow resistance is explained in terms of internal and external frictions. The external friction is always encountered along the channel boundary included in the momentum equation. The internal friction on the other hand occurs due to a velocity gradient within the cross-sectional area. The friction slope is always defined with S_o, as the boundary friction per unit weight of the water present in the channel within the flow area and the wetted perimeter.

Gradually varied flow

A flow control is any feature composed of the relationship between depth and discharge in a channel. A critical flow section is a kind of flow control, since the Fr =1. Hydraulic features may also be used in controlling the flow through the installation of weirs and gates. In absence of flow control, the flow in an open channel tends to become normal; the flow depths varies between two controls, which is referred to as gradual non-uniform flow. Gradually varied flow may be defined by the following equation,

$$H = Z_b + y + \frac{V^2}{2G}$$

Where Z_b = elevation of bottom channel

Y = flow depth

V = average cross-sectional velocity

G = gravitational acceleration

Findings and assessment

The manning equation was used to calculate and estimate flow rates, which provided a design allowance of 1.2 meters for freeboard. According to literature, the data has been used in the plotting of graphs as well as drawing of the longitudinal cross-section profile, which typically illustrates the components of the channel (Wang, Chen, X., Chen, & You, 2018, p. 55). The overall design of the channel utilized fundamental principles of drainage, such as the use of the Froude number, critical flow and the flow resistance, which are key aspects that may help to increase the efficiency of the channel. The provision of important elements such as Reynolds number assists in determining the flow regime as well as defining the resistance forces encountered by the flowing fluid (James, 2018, p. 45).

Conclusion

In conclusion, the channel is designed to control flooding, represented by the detailed calculation of the peak discharge of the channel. The application of equations such as the manning equation has helped in determining the required parameter that will suit the overall design of a channel. In this regard, to ensure that the efficiency of the channel flow is maintained throughout its cause channel, the design should incorporate fundamental flow principles characterized by the application of the Froude number and critical flow consideration, as well as the flow resistance.

References

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Appendix

Channel flow area