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Best Hydraulic Sections for Open Channels employing Spread Sheets

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ABSTRACT

The best hydraulic section of an open channel is characterized by provision of maximum discharge with a given cross sectional area. In fact, the choice of best hydraulic section also possesses other advantages than hydraulic performance. For instance, for a given discharge rate the use of best hydraulic section could guarantee the least cross sectional area of the channels. Substantial savings could be made from the reduction in the amount of excavation and from the use of less channel linings.

To obtain the best hydraulic channel section, some variables have to be determined. For a flow equation, e.g. Manning, the channel section contains two variables (rectangular and triangular sections) or three variables (trapezoidal and round-bottom triangular sections). For a given flow, the best hydraulic channel section can be obtained by minimizing the wetted perimeter (or the cross-sectional area). Any flow equation, e.g. Manning, can be used. There are many conventional methods given in the textbooks.

In this paper, Manning equation will be used to get the best hydraulic section for a trapezoidal section for open channels with different side slopes. Also, Microsoft Excel software is employed as a spread sheet to obtain the required best hydraulic sections. Definitely, samples are included to obtain the best hydraulic section for trapezoidal channel with side slopes of 1:1, 3:2, and 2:1.

Beside the basic solution obtaining the best hydraulic section, an additional solution is included. This additional solution is characterized by modifying the bed width (b) to the nearest 5 cm, and then it gives the modified water depth for the same flow area.

Also, a second additional solution may be used concerning the velocity of water through the trapezoidal best hydraulic section. This additional solution is characterized

by calculating the velocity of the water through the channel section. For earth channels, the water velocity is likely non-silting non-scouring velocity. That is the velocity is not less than 0.3 m/sec to avoid silting, and is not more than 0.9 m/sec to avoid scouring. The second additional solution calculates the velocity, and then it modifies the area of flow to keep the velocity, and finally it obtains the corresponding values for the bed width and the water depth.

It is found that this design of best hydraulic sections is efficient, accurate, easy and simple. It can be widely used by students and engineers to obtain the best hydraulic section for any trapezoidal channel in hydraulics, irrigation canals, and drains.

It is recommended to apply the same technique to obtain the best hydraulic sections for other triangular and circular open channels. Also, it is recommended to investigate the application of this technique to design the non silting non scouring sections for canals and drains of irrigation projects.

INTRODUCTION

The best hydraulic section of an open channel is characterized by provision of maximum discharge with a given cross sectional area. In fact, the choice of best hydraulic section also possesses other advantages than hydraulic performance. For instance, for a given discharge rate the use of best hydraulic section could guarantee the least cross sectional area of the channels. Substantial savings could be made from the reduction in the amount of excavation and from the use of less channel linings.

To obtain the best hydraulic channel section, some variables have to be determined. For any flow equation, e.g. Manning, the channel section contains two variables (rectangular and triangular sections) or three variables (trapezoidal and round-bottom triangular sections). For a given flow, the best hydraulic channel section can be obtained by minimizing the wetted perimeter (or the cross-sectional area). Any flow equation, e.g. Manning, can be used. There are many conventional methods given in the textbooks.

In this paper, Manning equation will be used to get the best hydraulic section for a trapezoidal section for open channels with different side slopes. Also, Microsoft Excel software is employed as a spread sheet to obtain the required best hydraulic sections. Definitely, cases are included to obtain the best hydraulic section for trapezoidal channel with side slopes of 1:1, 3:2, and 2:1.

BEST HYDRAULIC TRAPEZOIDAL SECTION FOR OPEN CHANNEL

For the trapezoidal section of an open channel shown in figure 1, the Manning equation for the flow is:

$$Q = \frac{1}{n} R^{2/3} S^{1/2} A$$

Where: Q = discharge, m^3/sec
n = roughness coefficient
R = hydraulic radius = A / P, m
A = area of water of the section, m^2
$A = b\,y + z\,y^2$
b = bed width, m
y = water depth, m
P = wetted perimeter of the section, m
$P = b + 2\,y\sqrt{1 + z^2}$
z = side slope
S = slope of the bed of the channel, cm/km

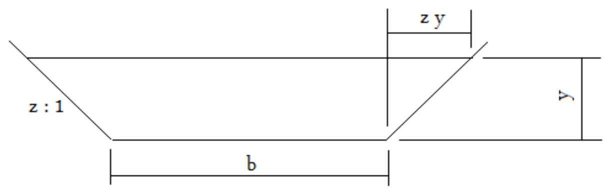

Figure 1 – Typical trapezoidal cross section for an open channel.

The roughness coefficient n depends on the conditions and the material where the channel is established. The hydraulic radius depends on both the area of the flow and the wetted perimeter of the section, that both are functions of the bed width b, the water depth y, and the slope z of the sides of the section.

The side slopes of the section depend on the engineering properties of the material through which the open channel is excavated. Mainly, the side slopes are 1:1 for earth with stone lining or earth for large channels, 3:2 for clay or earth for small ditches, and 2:1 for sandy earth. (Chow, 1959).

The longitudinal slope S is the slope of the channel along its length. It can be taken equal to the slope of the water surface i, when it is known. That is to maintain a uniform flow of water through the channel.

The best hydraulic section can be obtained mainly for a given value of z by minimum wetted perimeter. That is to differentiate the wetted perimeter with respect to the water depth y. Thus the condition for the best hydraulic trapezoidal cross section is that the length of the sloping side is equal to half the top width of the section. That is: $b = 2\,y\,(\sqrt{1 + z^2} - z)$

BEST HYDRAULIC TRAPEZOIDAL SECTION EMPLOYING SPREAD SHEETS

Substituting the value of z in the last equation, a relation between the bed width b and the water depth y is established for the best hydraulic trapezoidal section. Microsoft spread sheet software Excel is employed in this paper to get the dimensions b and y of the best hydraulic trapezoidal section, according to each value of z. The data of Q, n, S are given, and the obtained basic solution includes the auto calculated values for y, b, A, P, R, and T.
The following examples illustrate the basic solution for the best hydraulic trapezoidal section for the cases of z = 1, z = 1.5, and z = 2.

Section 1	**Section Number**
20	**Water Surface Slope "i" (cm/km)**
0.0002	**Bed Slope "*S* = *i*" (m/m)**
1.91	**Discharge "*Q*" (m^3/sec)**
40	**1 / Manning Coefficient "*1 / n*"**
For Best Hydraulic Section	**x' = T / 2 & z = 1 & b = 0.82 y**

Basic Solution

1.5006	**Water Depth "y" (m)**
1.2305	**Bed Width "b" (m)**
4.098223631	**Cross Sectional Area "*A*" (m^2)**
5.477154568	**Wetted Perimeter "*P*" (m)**
0.748239543	**Hydraulic Radius "*R* = *A* / *P*" (m)**
4.231664625	**Top Width "T" (m)**

Additional Solution for Modified Bed Width, to nearest 5 cm

4.098223631	**Cross Sectional Area "*A*" (m^2)**
1.30	**Modified Bed Width "b_m" (m)**
1.48	**Modified Water Depth "y_m" (m)**
5.48	**Modified Wetted Perimeter "*P*" (m)**
0.75	**Modified Hydraulic Radius "*R* = *A* / *P*" (m)**
4.25	**Top Width "T" (m)**

Figure 2 – Best Hydraulic Trapezoidal Section for Open Channel, z = 1.

Section 2	**Section Number**
20	**Water Surface Slope "i" (cm/km)**
0.0002	**Bed Slope "*S* = *i*" (m/m)**
1.91	**Discharge "*Q*" (m^3/sec)**
40	**1 / Manning Coefficient "*1 / n*"**
For Best Hydraulic Section	**x' = T / 2 & z = 1.5 & b = 0.61 y**

Basic Solution

1.4186	**Water Depth "y" (m)**
0.8653	**Bed Width "b" (m)**
4.246024572	**Cross Sectional Area "*A*" (m^2)**
5.986355101	**Wetted Perimeter "*P*" (m)**
0.70928378	**Hydraulic Radius "*R* = *A* / *P*" (m)**
5.121028889	**Top Width "T" (m)**

Additional Solution for Modified Bed Width, to nearest 5 cm

4.246024572	**Cross Sectional Area "*A*" (m^2)**
0.90	**Modified Bed Width "b_m" (m)**
1.41	**Modified Water Depth "y_m" (m)**
5.99	**Modified Wetted Perimeter "*P*" (m)**
0.71	**Modified Hydraulic Radius "*R* = *A* / *P*" (m)**
5.13	**Top Width "T" (m)**

Figure 3 – Best Hydraulic Trapezoidal Section for Open Channel, z = 1.5.

Section 3		**Section Number**
20		**Water Surface Slope "i" (cm/km)**
0.0002		**Bed Slope "*S* = *i*" (m/m)**
1.91		**Discharge "*Q*" (m^3/sec)**
40		**1 / Manning Coefficient "*1 / n*"**
For Best Hydraulic Section		**x' = T / 2 & z = 2 & b = 0.47 y**
Basic Solution		
1.3371		**Water Depth "y" (m)**
0.6284		**Bed Width "b" (m)**
4.41604553		**Cross Sectional Area "*A*" *(m^2)***
6.605341008		**Wetted Perimeter "*P*" (m)**
0.668556782		**Hydraulic Radius "*R* = *A* / *P*" (m)**
5.976897633		**Top Width "T" (m)**
Additional Solution for Modified Bed Width, to nearest 5 cm		
4.41604553		**Cross Sectional Area "*A*" *(m^2)***
0.70		**Modified Bed Width "b_m" (m)**
1.32		**Modified Water Depth "y_m" *(m)***
6.61		**Modified Wetted Perimeter "*P*" (m)**
0.67		**Modified Hydraulic Radius "*R* = *A* / *P*" (m)**
5.98		**Top Width "T" (m)**

Figure 4 – Best Hydraulic Trapezoidal Section for Open Channel, z = 2.

In the last three examples, an additional solution can be obtained in order to get a modified bed width to the nearest 5 cm, if needed. In this case, the additional solution obtains the values for both the modified bed width b_m and the modified water depth y_m for the same cross sectional area of the flow A, and then it gives the values of the corresponding P, R, and T.

VELOCITY OF WATER THROUGH THE BEST HYDRAULIC TRAPEZOIDAL SECTION EMPLOYING SPREAD SHEETS

A second additional solution may be used concerning the velocity of water through the trapezoidal best hydraulic section. This additional solution is characterized by calculating the velocity of the water through the channel section. For earth channels, the water velocity is likely non-silting non-scouring velocity. According to the standards and conditions of irrigation in Egypt, this velocity is not less than 0.3 m/sec to avoid silting, and it is not more than 0.9 m/sec to avoid scouring. The second additional solution calculates the velocity, and then it modifies the area of flow to keep the non-silting non-scouring velocity, and finally it obtains the corresponding values for the bed width b and the water depth y.

The following two examples illustrate how to keep the velocity of water within the required range for non-silting non-scouring conditions. The velocity is calculated first according to the cross section area A obtained by the basic solution. The velocity may be within the required range. Otherwise, if the velocity is less than 0.3 m/sec, it is assumed that the velocity is 0.3. Consequently, the modified value for the cross section area A_m is auto calculated first, and then the corresponding values for the modified bed width b_m, the modified water depth y_m, and the modified velocity v_m are auto calculated too.

Section 4	**Section Number**
20	**Water Surface Slope "i" (cm/km)**
0.0002	**Bed Slope "*S = i*" (m/m)**
29.91	**Discharge "*Q*" (m^3/sec)**
40	**1 / Manning Coefficient "*1 / n*"**
For Best Hydraulic Section	**x' = T / 2 & z = 1 & b = 0.82 y**

Basic Solution

4.2102	**Water Depth "y" (m)**
3.4524	**Bed Width "b" (m)**
32.26137977	**Cross Sectional Area "*A*" *(m^2)***
15.36733785	**Wetted Perimeter "*P*" (m)**
2.099347336	**Hydraulic Radius "*R = A / P*" (m)**
11.87284732	**Top Width "T" (m)**

Additional Solution for Modified Bed Width, to nearest 5 cm

32.26137977	**Cross Sectional Area "*A*" *(m^2)***
3.50	**Modified Bed Width "b_m" (m)**
4.19	**Modified Water Depth "y_m" *(m)***
15.37	**Modified Wetted Perimeter "*P*" (m)**
2.10	**Modified Hydraulic Radius "*R = A / P*" (m)**
11.89	**Top Width "T" (m)**

Additional Solution for Modified Water Velocity (0.3 < v < 0.9 m/sec)

0.927114718	**Velocity "v = Q / A" (m/sec)**
33.23333333	**Modified Cross Sectional Area "A = Q / 0.9" (m^2)**
4.273180696	**Modified Water Depth "y_m" (m)**
3.504008171	**Modified Bed Width "b_m" (m)**
0.9	**Modified Velocity "v" (m/sec)**

Figure 5 – Best Hydraulic Trapezoidal Section with Non-Scouring Water Velocity.

Section 5	Section Number
20	Water Surface Slope "i" (cm/km)
0.0002	Bed Slope "$S = i$" (m/m)
0.21	Discharge "Q" (m^3/sec)
40	1 / Manning Coefficient "$1 / n$"
For Best Hydraulic Section	x' = T / 2 & z = 1 & b = 0.82 y

Basic Solution

0.6557	Water Depth "y" (m)
0.5377	Bed Width "b" (m)
0.782501356	Cross Sectional Area "A" (m^2)
2.393314213	Wetted Perimeter "P" (m)
0.326953039	Hydraulic Radius "$R = A / P$" (m)
1.849081118	Top Width "T" (m)

Additional Solution for Modified Bed Width, to nearest 5 cm

0.782501356	Cross Sectional Area "A" (m^2)
0.60	Modified Bed Width "b_m" (m)
0.63	Modified Water Depth "y_m" (m)
2.39	Modified Wetted Perimeter "P" (m)
0.33	Modified Hydraulic Radius "$R = A / P$" (m)
1.87	Top Width "T" (m)

Additional Solution for Modified Water Velocity ($0.3 < v < 0.9$ m/sec)

0.268370142	Velocity "v = Q / A" (m/sec)
0.7	Modified Cross Sectional Area "A = Q / 0.3" (m^2)
0.620173673	Modified Water Depth "y_m" (m)
0.508542412	Modified Bed Width "b_m" (m)
0.3	Modified Velocity "v" (m/sec)

Figure 6 – Best Hydraulic Trapezoidal Section with Non-Silting Water Velocity.

CONCLUSIONS AND RECOMMENDATIONS

It is found that the design of best hydraulic trapezoidal sections for open channels employing spread sheets is efficient, accurate, easy and simple. It can be widely used by students and engineers to obtain the best hydraulic section for any trapezoidal open channel. Also, it is obvious that this design can be implemented governing the water velocity to be within the required range to avoid scouring and silting in irrigation canals and drains of irrigation projects.

It is recommended to apply the same technique to obtain the best hydraulic sections for circular and other sections for open channels.

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