2. CHANNELS AND THEIR GEOMETRIC PROPERTIES

2.1 INTRODUCTION

An open channel is a physical system in which water flows with a free surface at the atmospheric pressure. In other words the pressure is impressed on free surface. A channel can be classified as either natural or artificial channel according to its origin.

Natural channels include all watercourses of varying sizes from tiny hillside rivulets, streams, small and large rivers to tidal estuaries that exist naturally on the earth. Subsurface streams carrying water with a free surface are also treated as natural open channels.

The cross sections of natural channel are irregular and hence hydraulic properties may vary from section to section, and reach to reach. A comprehensive study of the behavior of flow in natural channels (the mobile boundaries) requires knowledge of other fields, such as hydrology, geomorphology and sediment transportation. Generally, these aspects are dealt in detail in river mechanics (fluvial hydraulics).

Artificial channels are those constructed or developed by human effort such as gutters, drainage, ditches, floodways, tunnels, log chutes, navigation channels, power canals and trough, spillways including model channels that are built in the laboratory for experimental investigation studies. Long distance canals have been constructed to achieve the interbasin transfer of water at National and International levels.

The artificial channel is known by different names, such as " canal "," chute", "culvert", "drop", "flumes" and "open - flow tunnel", Aqueduct.

However, these names, are used rather loosely and can be defined only in very general manner.

The canal is usually a long and mild-sloped channel built in the ground, which may be lined or unlined with stone masonry, concrete, cement, wood or bituminous materials etc.

Eg: Ganga Canal, Indira Gandhi Canal, Narmada Canal.

The chutes are a channel having steep slopes. The culvert, flowing partly full, is a covered channel of comparatively short length provided for draining water across roadways and through railway embankments.

The drop is similar to chute, but the change in elevation is effected with in a short distance.

The flume is a channel of wood, metal, fiber reinforced plastic, concrete, or masonry, usually supported on or above the surface of the ground to carry water across a depression.

The open -flow tunnel, fall, is a comparatively long covered channel used for carry water through a hill or any obstruction on the ground. Normally these artificial canals are with rigid boundaries.

The channels can be classified as prismatic and nonprismatic. A channel built with constant cross section and constant bottom slope and fixed alignment is named as prismatic channel. Otherwise, the channel is nonprismatic.

Example: spillway having variable width and canals curved alignment. (Meandering).

The term channel section refers to the cross section of channel taken normal to the direction of the flow.

A vertical channel section, however, is the vertical section passing through the lowest or bottom point of the channel section. For horizontal channels, therefore, the channel section is always a vertical channel section.

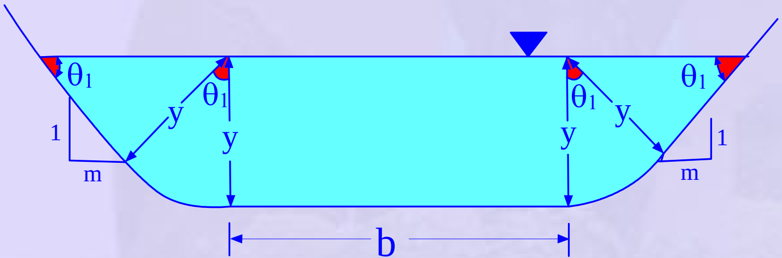
Natural sections are in general very irregular, usually varying from an approximate parabola to an approximate trapezoid shapes and for streams subject to frequent floods, the channel may consist of a main channel section carrying normal discharges and one or more side channel sections for accommodating overflows. These are called compound channel.

Artificial channels are usually designed with sections of regular geometrical shapes.

Table gives the geometric properties for the cases of rectangular, trapezoidal, triangular, circular, parabolic channels. In addition the details of Round bottomed triangular and round bottom rectangular are also given.

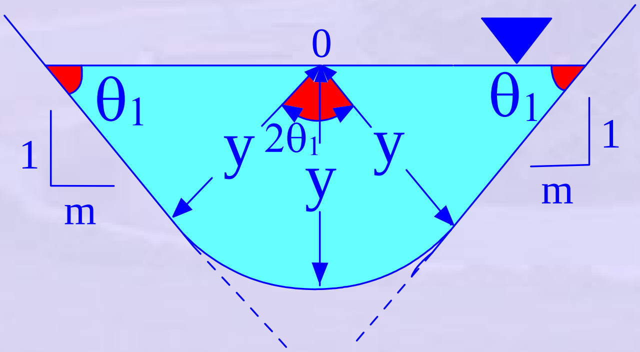
2.1.2 Geometrical Properties

Unlined trapezoidal section is the most common channel section used in the field for it provides side slopes for stability. The rectangular channel with an angle 90° and triangular channel with a bed width equal to zero are special cases of the trapezoidal channel. Since the rectangular channel has vertical sides, it is commonly used for channels built of materials, such as lined masonry, rocks, metal, or timber. Precast concrete sections are also used for small size canals. The triangular section is used only for small ditches, roadside gutters, and for experimental investigations in the laboratory. The circular shape is the popular section for sewers and culverts of small and medium sizes. The parabola is used as an approximation for section of small and medium- size natural channels. Practical sections are also used as shown in figure (as recommended by Central Board of Irrigation and Power).



$$A = by + y^2\,(\,\theta_1 + \mathrm{Cot}\theta_1)$$
$$P = b + 2y(\,\theta_1 + \mathrm{Cot}\theta_1)$$
$$R = \frac{by + y^2\,(\,\theta_1 + \mathrm{Cot}\theta_1)}{b + 2y\,(\,\theta_1 + \mathrm{Cot}\theta_1)}$$

Lined channel section for Q > 55 m^3/s

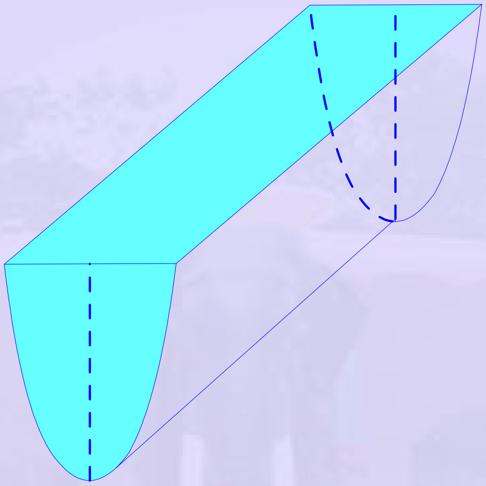


$$A = 2(1+y^2\mathrm{Cot}\theta_1) + \frac{1}{2}y^2 2\theta_1$$
$$= y^2(\theta_1 + \mathrm{Cot}\theta_1)$$
$$P = 2y\mathrm{Cot}\theta_1 + 2y\theta_1 = 2y(\theta_1 + \mathrm{Cot}\theta_1)$$
$$R = \frac{A}{P} = \frac{y^2(\theta_1 + \mathrm{Cot}\theta_1)}{2y(\theta_1 + \mathrm{Cot}\theta_1)} = \frac{y}{2}$$

Lined channel section
for Q < 55 m^3 / s

Closed geometric sections other than circular section are frequently used in sewer system, particularly for sewers large enough for a person to enter. These sections are given various names according to their form, they may be egg-shaped, ovoid, Semi-elliptical, U-shaped, catenary, horseshoe, basket-handle, etc. The complete rectangular and square are also common for large sewers.

A special geometric section known as hydrostatic catenary or lintearia is the shape of the cross section of trough, formed of flexible sheets of negligible weight, filled with water upto the top of the section, and firmly supported at the upper edges of the sides but with no effects of fixation. The hydrostatic catenary has been used for the design of the section of some elevated irrigation flumes in UK (United Kingdom). These flumes are constructed of metal plates so thin that their weight is negligible, and are firmly fixed to beams at the upper edges.



Cartesian equation: $y = a \cosh(x/a)$

Hydrostatic Catenary

[Click here for Geometric elements of channel sections]

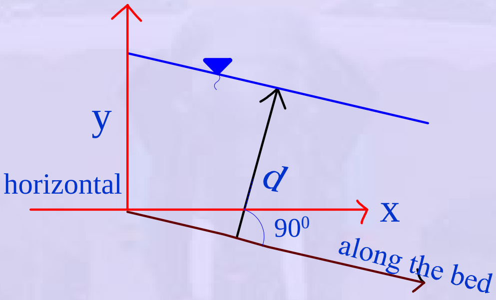
Geometric elements are properties of a channel section that may be defined entirely by the geometry of the section and the depth of flow. These elements are extensively used in computations of flows.

The geometric elements for simple regular channel sections can be expressed mathematically in terms of the depth of flow and other dimensions of the section. For complicated sections and sections of natural streams, however, no simple formula can be written to express these elements, but graphs representing the relation between these elements and the depth of flow can be prepared for use in hydraulic computations.

2.1.3 Definitions of several geometric elements of basic importance are given below

Depth of flow

The depth of flow y is the vertical distance from the lowest point of channel cross section to the free surface. This term is often used interchangeably with the depth of flow section. Strictly speaking, the depth of flow section is the depth of flow normal to the direction of flow, or the height of the channel section containing the water. For a channel with a longitudinal slope angle θ, it can be seen that the depth of flow is equal to the depth of flow section divided by. In the case of steep channels, therefore, the two terms should be used discriminately.



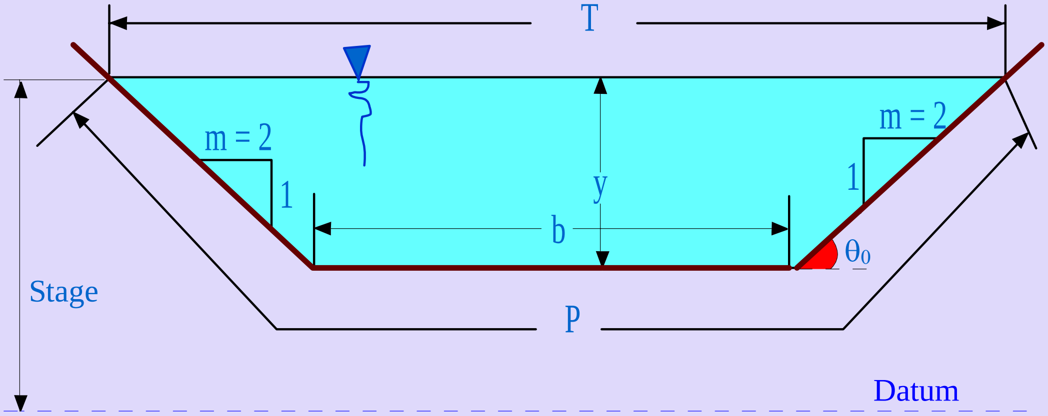
Normal and vertical depths

Box

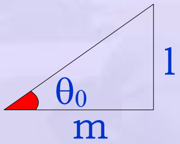
$\theta = 10^{o}$, $\cos\theta$ = 0.9848,thus there would be an error of 1.51%.

$y = d \cos\ \theta$

If x is measured along the horizontal direction instead of the sloping bed, then the 2% error occurs at about $\theta = 11^{\circ}\ or\ S_o = 0.20$. On the other hand if x is measured along the sloping bed instead of the horizontal 2% error occurs at about $\theta = 16^{o}$ or $S_o = 0.29$, which is an extremely steep slope in open channels. However, there is exception in cases such as spill ways, falls, chutes.

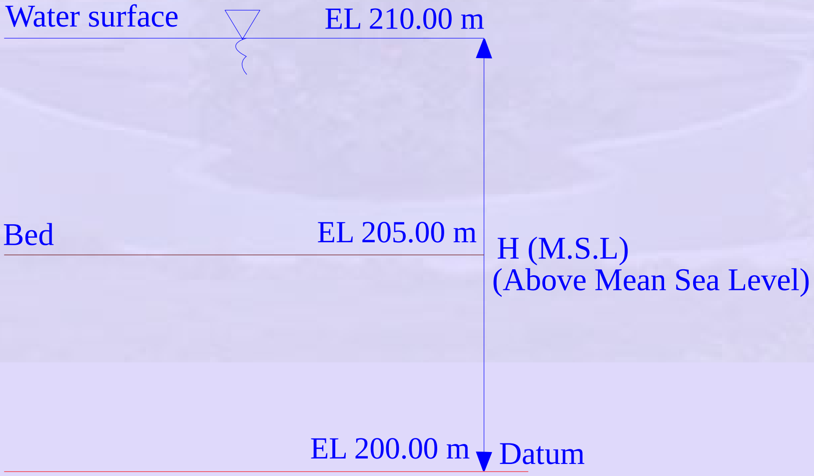


A = Area of flow
T = free surface width (m)
m = side slope defined in horizontal to 1 vertical; m:1
$m = \cot\theta$



P = Wetted perimeter is the boundary which is in contact with the flow (m)
b = bed width in (m)
y = depth of flow

A Channel cross section



Definition of stage

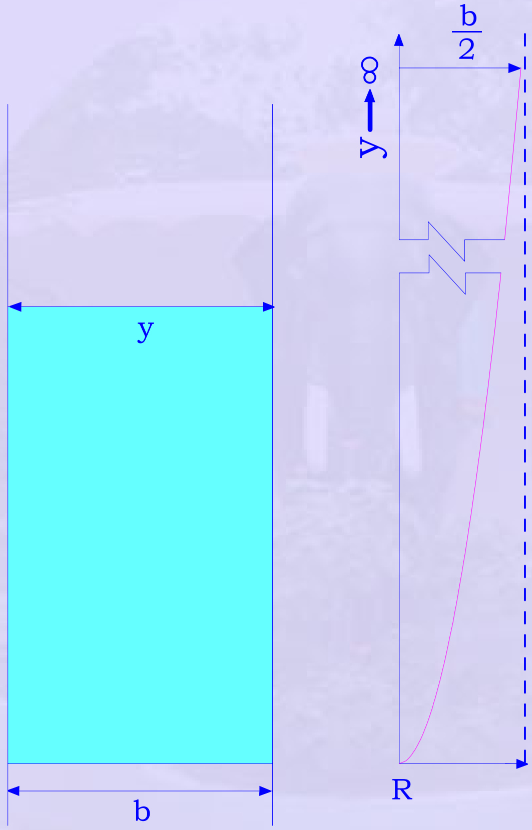
The stage H is the elevation or vertical distance of the free surface above the datum. If the lowest point of the section is chosen as the datum, the stage is identical with the depth of flow. Free surface width T is the width of channel section at the free surface.

$$T \approx \frac{dA}{dy}$$

The water flow area A is the cross-sectional area of the normal to the direction of flow.

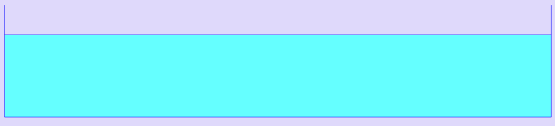
The wetted perimeter P is the length of the line of intersection of the channel wetted surface with a cross sectional plane normal to the direction of flow.

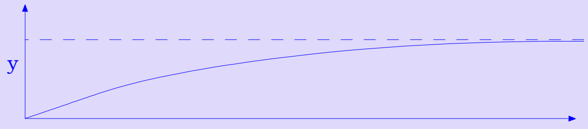
The hydraulic mean radius R is the ratio of the water flow area to its wetted perimeter, $R = \frac{A}{P}$ When a shallow channel of b is used and $y \to \infty$ then $R \to \frac{b}{2}$.



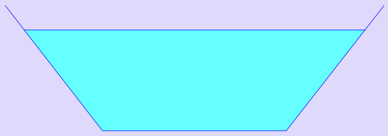
$$y \rightarrow \infty \text{ then } R \rightarrow \frac{b}{2}$$

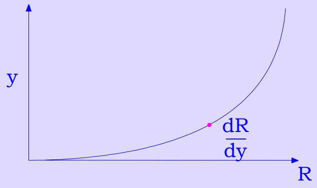
Hydraulic mean radius





$b \rightarrow \infty$ $R \rightarrow y$ $R \rightarrow \infty$



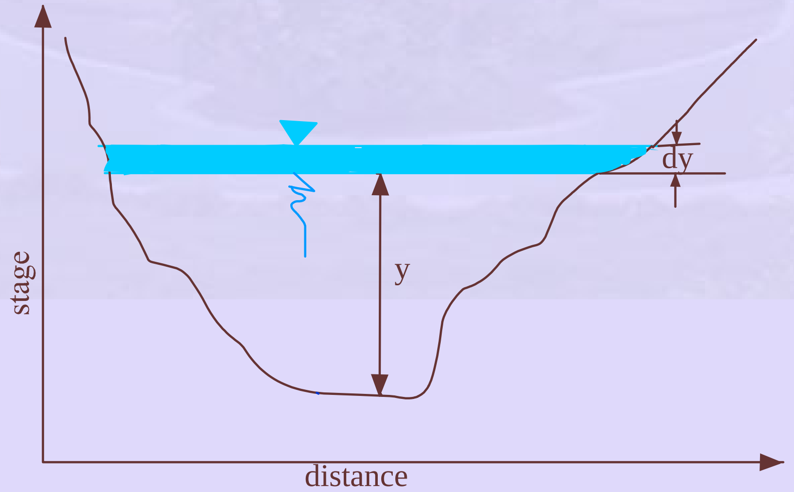


The hydraulic mean depth D is the ratio of the water area to the free surface width, $D = \frac{A}{T}$. The section factor for critical- flow computation m is the product of the water area and the square root of the hydraulic depth, $Z = A\sqrt{D} = A\sqrt{\frac{A}{T}}$. The section factor S.F for uniform-flow computation in case of Manning formula is the product of the water area and the two-thirds power of the hydraulic radius $S.F = AR^{\frac{2}{3}}$ other wise for chezy's formula it is i.e., $AR^{\frac{2}{3}}$. The details of circular channel are given in OPEN - CHANNEL HYDRAULICS by VEN TE CHOW - pp 632 - 639(1959).

Earlier the nomographs for trapezoidal and parabolic sections were used for specific side slopes see reference. The geometrical characteristic of the irregular cross section can be obtained using a set of co - ordinates describing the cross section, with the help of interpolation between any inter mediate depth. The typical programme is given in the appendix. The computations can be done either by from top or from the bottom most point.

Actual area up to depth y =Total area A - dA

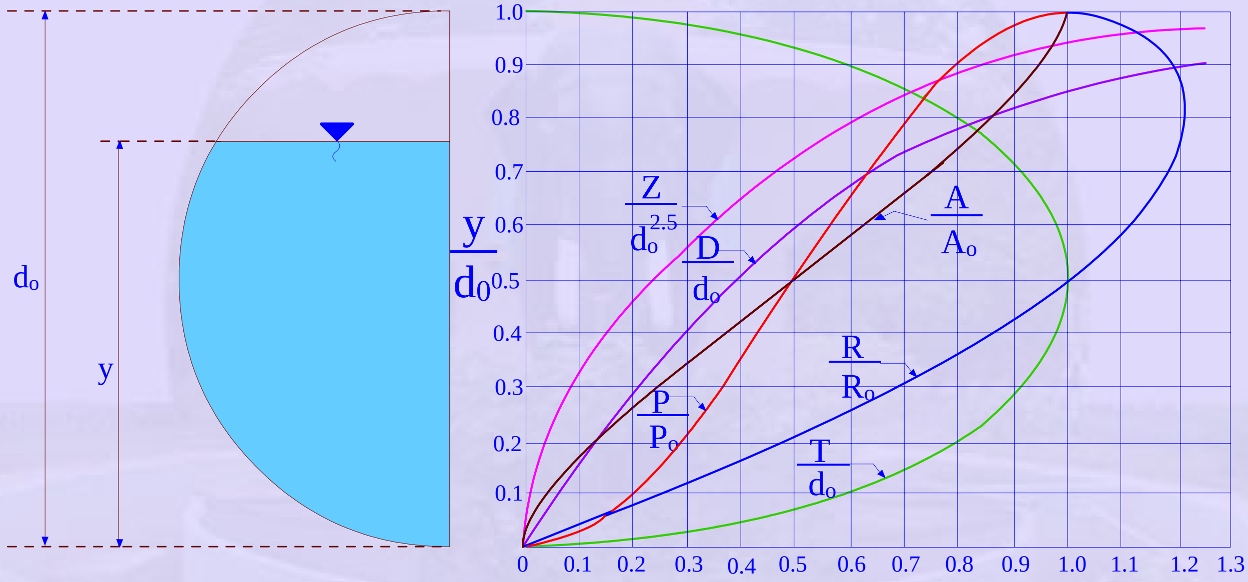
Area up to (y + dy) = Area up to y +dA



River bed elevation as a fuction of distance from the river bank

2.1.4 Circular channel

Normalised geometric characteristics are shown in figure. When the flow is full the hydraulic mean radius is $\frac{1}{4}d_o$ (i.e) $\left(\frac{A}{P}=\frac{\frac{\pi d_o^2}{4}}{\pi d_o}=\frac{d_o}{4}\right)$ which is less than the maximum hydraulic mean radius which occurs at $0.81d_o$ when relative velocity of the flow is considered for constant Manning roughness coefficient. similarly it is $0.938d_o$ (click) for maximum value of $AR^{\frac{2}{3}}$ when the discharge is maximum.



$$P_o=\pi d_o \qquad A_0=\frac{\pi d_o^2}{4} \qquad R_0=\frac{d_o}{4}$$

Subscript zero indicates full flow condtion

Normalized geometric elements for a circular section

Problem: Write a computer program to obtain the geometrical elements of a circular shape channel and obtain the $\frac{y}{d_0}$ Vs $\frac{AR^{2/3}}{A_0R_0^{2/3}}$

Compute the geometric elements, area, hydraulic mean radius, hydraulic mean depth for the following cases:

Rectangular channel: Bed width is 10 m, Depth of embankment is 15.15 m, Depth of flow is 8.870 m.

Trapezoidal channel: Bed width is 10 m, Depth of embankment is 15.15 m, Depth of flow is 7.77 m, side slope m:1 = 2:1.

Triangular channel: Depth of embankment is 15.15 m, Depth of flow is 9.75 m, side slope m:1 = 2:1.

Circular channel: Diameter is 15.15 m, Depth of flow is 6.47 m.

2.1.5 Natural channel

The depth of flow 7.567 m.

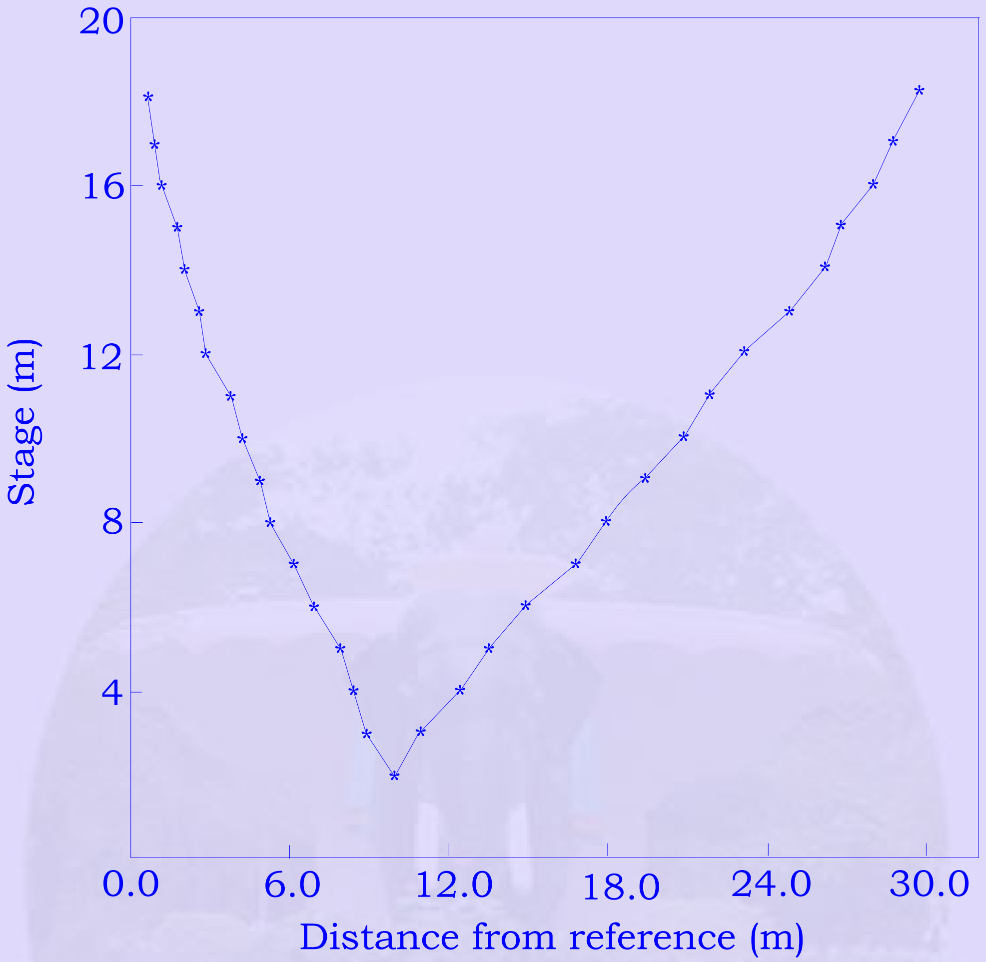
The program could be developed using spread sheet.

The INPUT for the natural channel is as follows

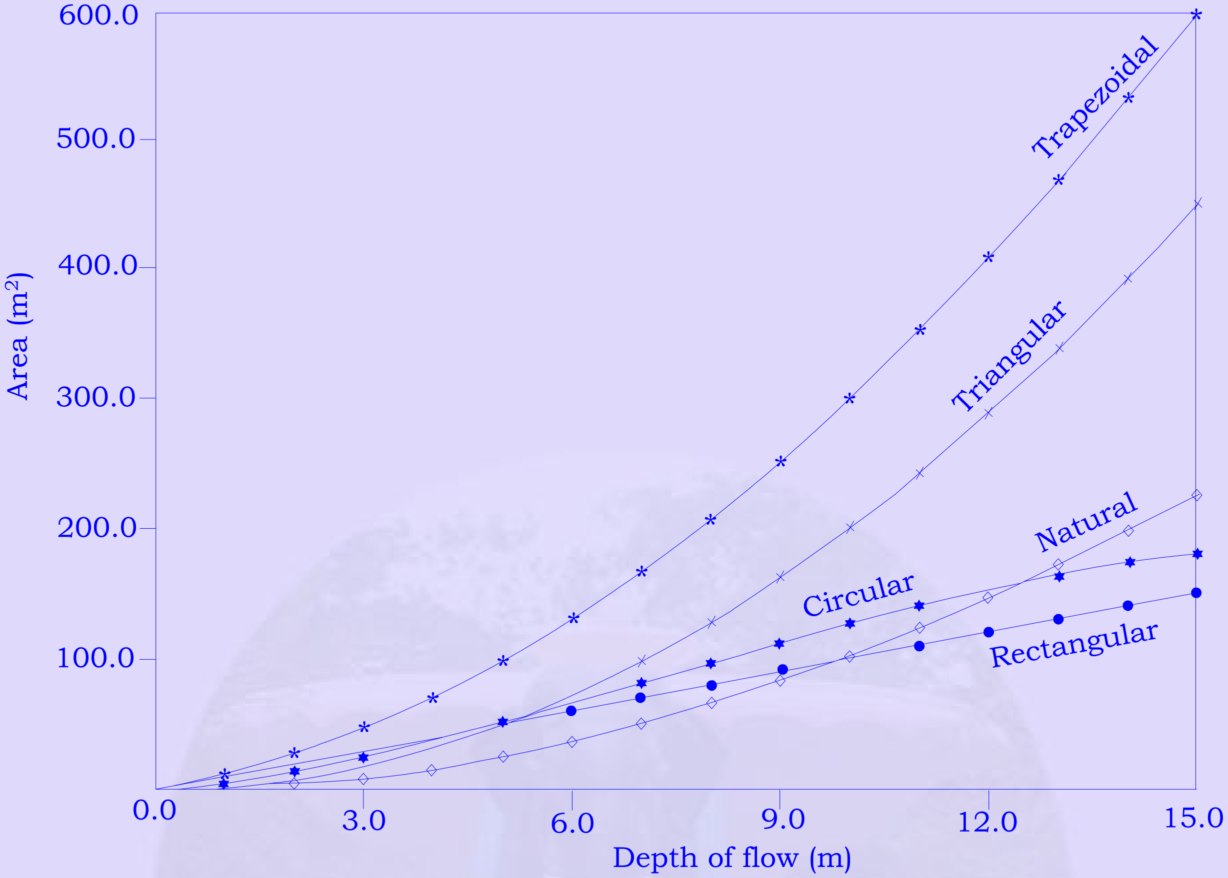
Stage of flow (m)	Distance of the embankments form reference	
	Left embankment	Right embankment (m)
2.000	10.000	10.000
3.000	9.000	11.000
4.000	8.500	12.500
5.000	8.000	13.600
6.000	7.000	15.000
7.000	6.300	16.900
8.000	5.400	18.000
9.000	5.000	19.500
10.000	4.300	21.000
11.000	3.900	22.000
12.000	3.000	23.300
13.000	2.700	25.000
14.000	2.200	26.300
15.000	1.900	27.000
16.000	1.300	28.200
17.000	1.000	29.000
18.150	0.700	30.000

The depth of flow = 7.567 m

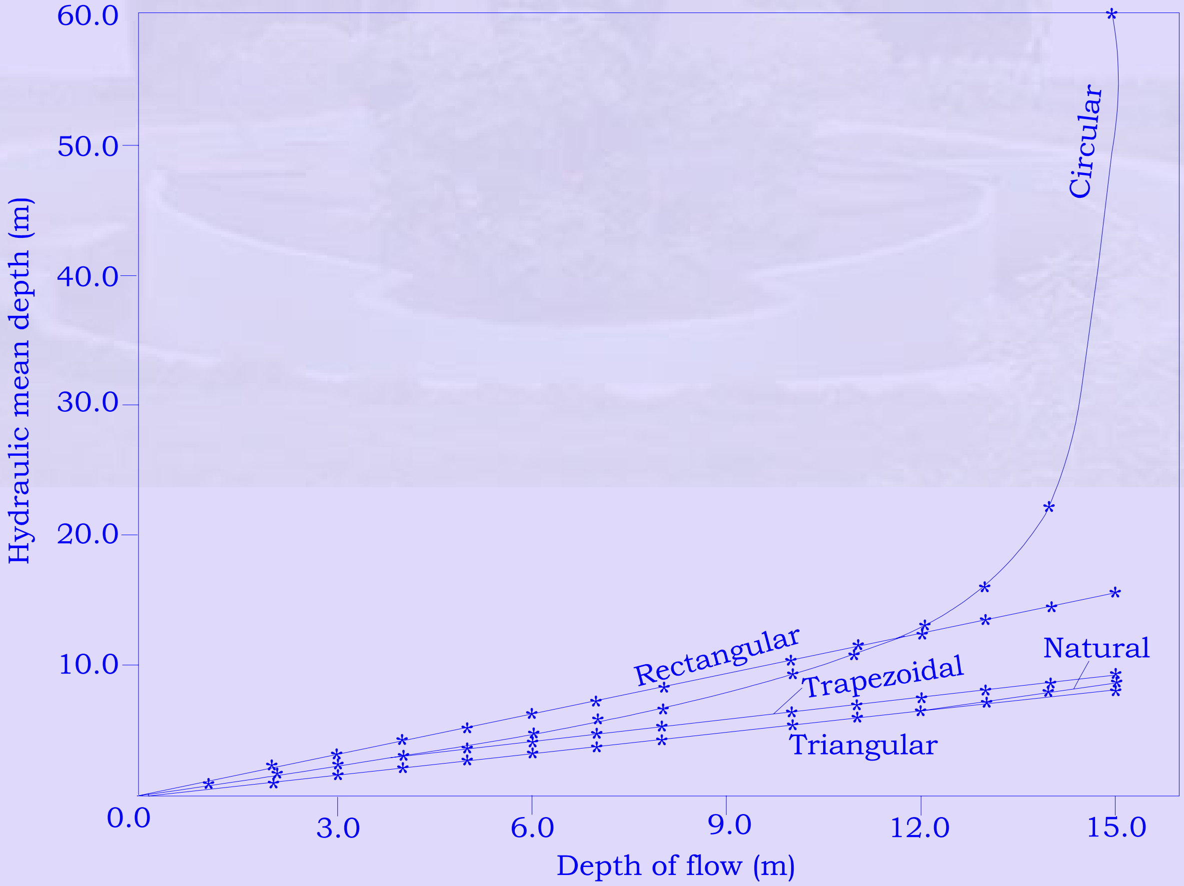
Solution:



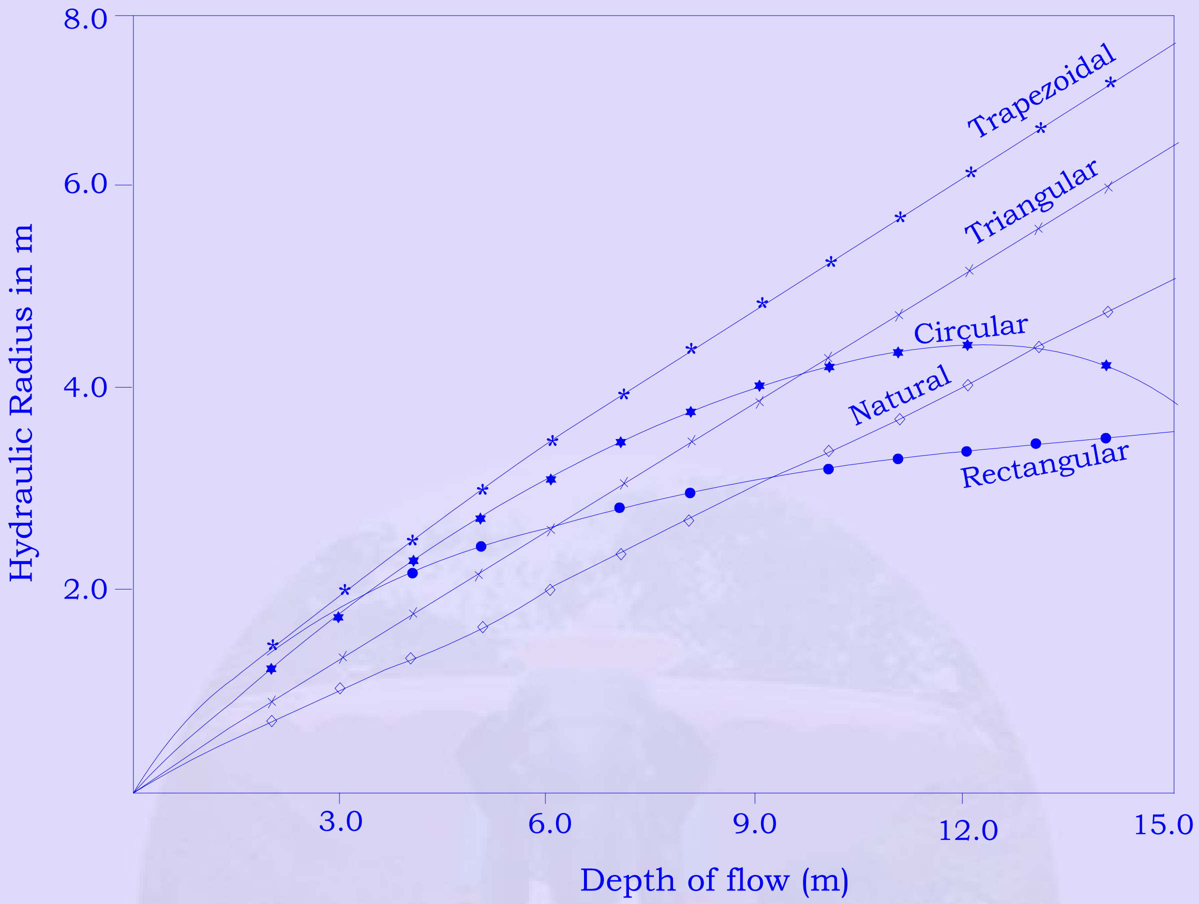
Natural channel



Variation of area with depth of flow



Variation of hydraulic mean depth with depth of flow

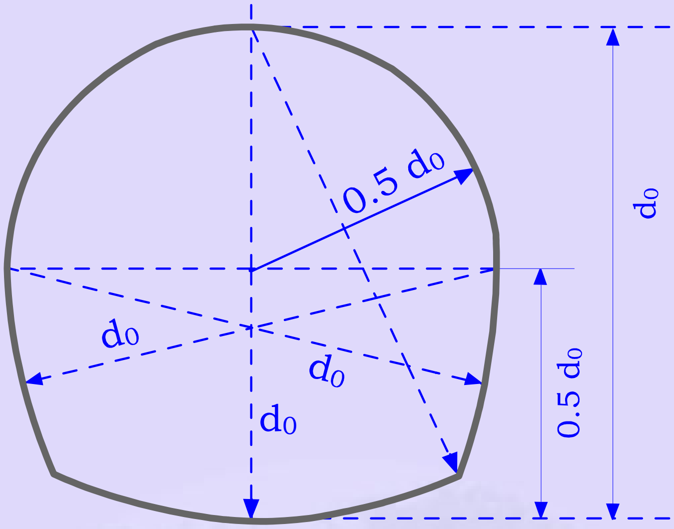


Variation of Hydraulic radius with the depth of flow

Table showing the geometrical elements for the above channels (metric units)

Section	y	A	P	T	R	D	$Z = A\sqrt{D}$
Trapezoidal	7.77	198.800	44.748	41.080	4.434	4.830	437.665
Rectangular	8.870	88.700	27.740	10.000	3.196	8.870	264.316
Triangular	9.750	190.500	43.603	39.000	4.360	4.875	421.324
Circular	6.470	73.488	21.575	14.954	3.397	4.910	163.428
Natural	7.567	58.895	39.0007	15.747	1.504	3.724	114.067

Problem: Compute the geometric elements for the horse shoe tunnel shown in figure below. Plot the normalised graphs representing the geometrical elements.



Horse shoe tunnel

If d_0 is 10 m and the depth of flow 7.5 m, what would be the area of flow, wetted perimeter, hydraulic mean radius, section factor for uniform flow.