

Comparison of pipe and open channel flow:

- a) Pipe flow fills entire conduit => a half full pipe is open channel flow, now closed conduit (pipe) flow
- b) Pipe flow has pressure (above or below atmospheric); open channel flow is always at atmospheric pressure
- c) Open channel flow has a free surface
- d) Open channel flow is driven by gravity whereas closed conduit flow responds to energy grade line

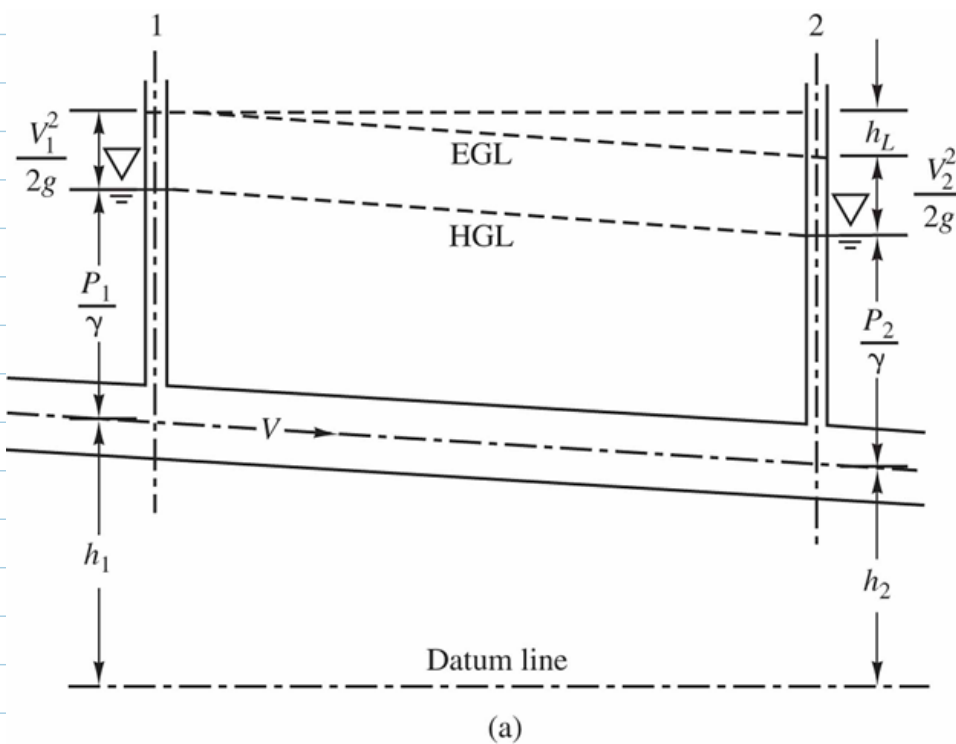
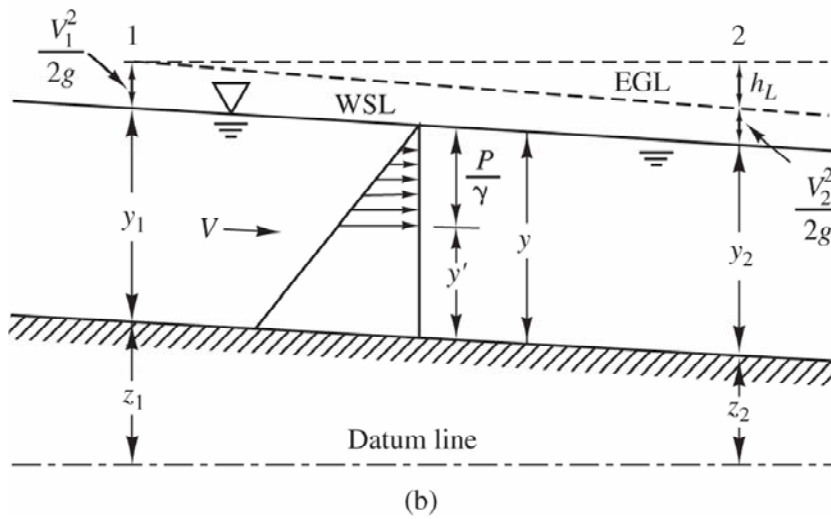


Figure 6.1 (continued) Comparison of: (b) open-channel flow



No pressure head
Depth, slope, velocity are
important



Definitions:

Flow area, cross sectional area of flow, A

Flow depth, y

Top width, T - width of channel at free surface

Wetted perimeter, P

Hydraulic depth (D) = A/T

Hydraulic Radius, $R = A/P$

Bottom slope, S_o

Side slope, $m = \text{vertical/horizontal}$

Bottom width, b

mostly we will deal with uniform flow

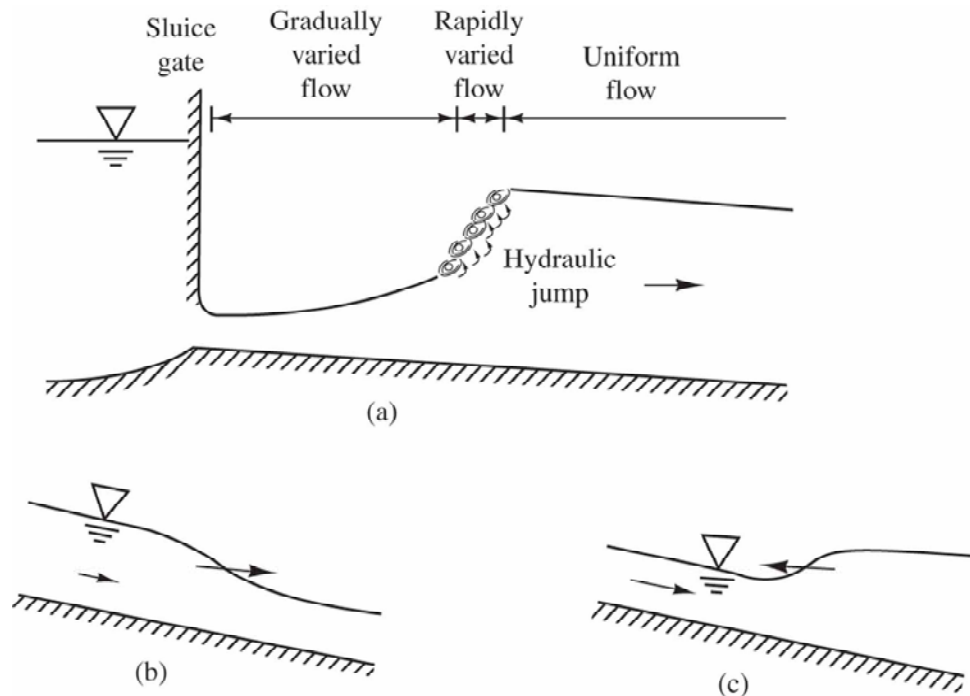
6.1

Wednesday, September 15, 2010
10:00 AM

Steady

Unsteady (transient), explain concept of stationary state - when flow rate down the channel changes slowly, relative to the rate at which the channel adjusts, one can model flow as steady

Figure 6.2 Classifications of open-channel flow: (a) gradually varied flow (GVF), rapidly varied flow (RVF), and uniform flow (UF); (b) unsteady varied flow; (c) unsteady varied flow

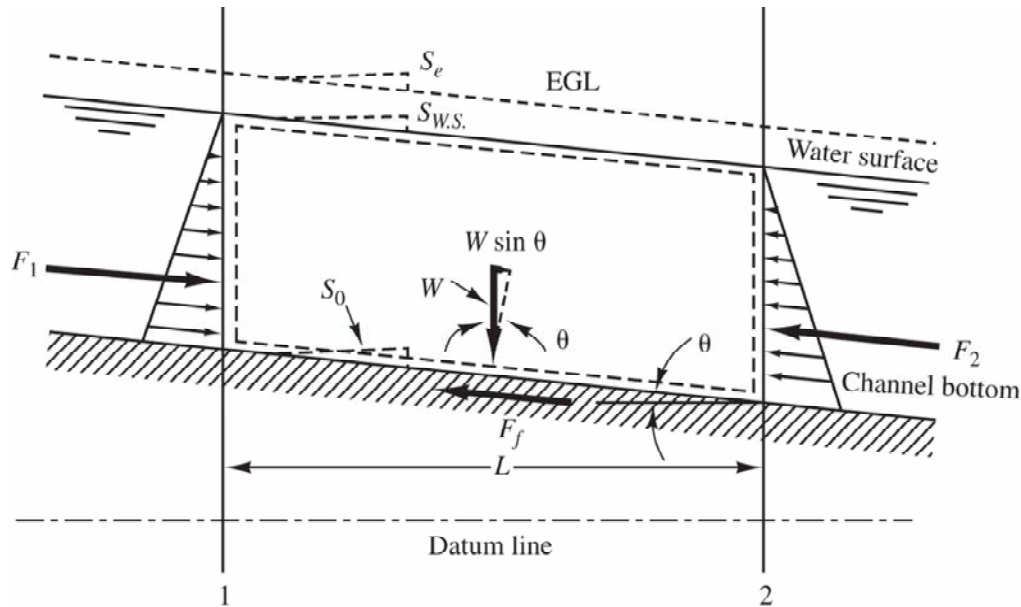


- a) Gradually and rapidly varied flow
- b) , c) Unsteady varied flow (flood waves and tidal bores)

6.2

Thursday, September 11, 2008
4:10 PM

Figure 6.3 Force components in uniform open-channel flow



PEARSON Fundamentals of Hydraulic Engineering Systems, Fourth Edition
Robert J. Houghtalen • A. Osman Akan • Ned H. C. Hwang

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Steady Uniform Flow in Open Channels

forces are gravity going down hill which is counteracted
by shear stress on the channel sides and bottom

weight of water is: $\gamma A L$

A = cross sectional area

L = length

γ = specific weight (62.4 lbf/ft³ or ρg or 9,810 N/m³)

The slope of a line in the plane containing the x and y axes is generally represented by the letter m , and is defined as the change in the y coordinate divided by the corresponding change in the x coordinate, between two distinct points on the line. This is described by the following equation:

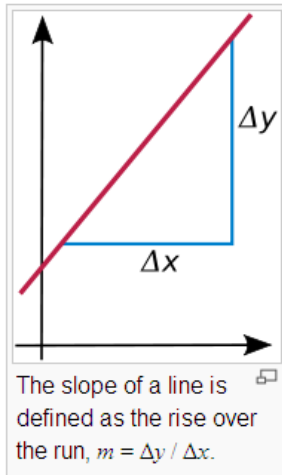
$$m = \frac{\Delta y}{\Delta x}.$$

(The *delta* symbol, " Δ ", is commonly used in mathematics to mean "difference" or "change".)

Given two points (x_1, y_1) and (x_2, y_2) , the change in x from one to the other is $x_2 - x_1$, while the change in y is $y_2 - y_1$. Substituting both quantities into the above equation obtains the following:

$$m = \frac{y_2 - y_1}{x_2 - x_1}$$

Pasted from <<http://en.wikipedia.org/wiki/Slope>>



if θ is the slope of the channel in degrees then the approximation

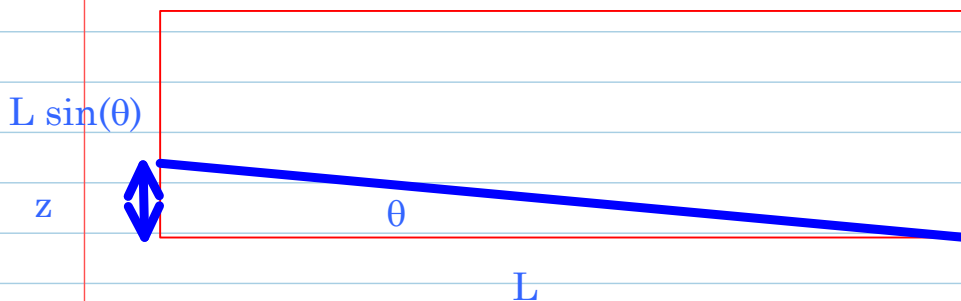
$$\sin(\theta) = \tan(\theta) = S_o \text{ is made}$$

note: the slope is technically the tangent (change in y over change in x)

the energy equation says that the vertical component of flow is the sine of the slope angle

$\sin \sim \tan$ for small angles

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$$\text{gravity force} = \gamma A L \sin(\theta) \sim \gamma A L \tan(\theta) = \gamma A L S_o$$

$$\text{friction force} = \tau P L$$

τ = shear stress on banks (N/m^2)

P = wetted perimeter

L = length of channel

define hydraulic radius as:

$R = A/P = \text{flow area/wetted perimeter}$

if shear stress is approximated by:

$\tau = KV^2$ where K is a constant and V is velocity

equating the forces (gravity forces = shear stress forces)

gives the Chezy equation:

$V = C(RS)^{0.5}$ where C is a constant that depends upon channel roughness

Manning rewrote this as:

$$V = (1/n)R^{0.66}S^{0.5}$$

$$\text{or } Q = AV = (1/n) A R^{0.66}S^{0.5}$$

<http://wwwrcamnl.wr.usgs.gov/sws/fieldmethods/Indirects/nvalues/index.htm>

The USGS site above has pictures of sites with values for the Manning's n

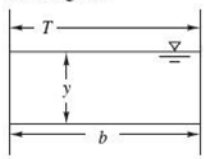
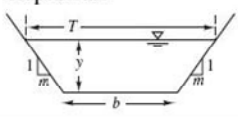
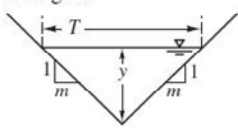
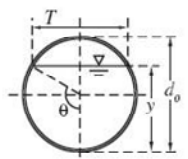
notice that for wide streams, the hydraulic radius is equal to the average depth

Material	Manning n	Material	Manning n
<i>Natural Streams</i>		<i>Excavated Earth Channels</i>	
Clean and Straight	0.030	Clean	0.022
Major Rivers	0.035	Gravelly	0.025
Sluggish with Deep Pools	0.040	Weedy	0.030
		Stony, Cobbles	0.035
<i>Metals</i>		<i>Floodplains</i>	
Brass	0.011	Pasture, Farmland	0.035
Cast Iron	0.013	Light Brush	0.050
Smooth Steel	0.012	Heavy Brush	0.075
Corrugated Metal	0.022	Trees	0.15
<i>Non-Metals</i>			
Glass	0.010	Finished Concrete	0.012
Clay Tile	0.014	Unfinished Concrete	0.014
Brickwork	0.015	Gravel	0.029
Asphalt	0.016	Earth	0.025
Masonry	0.025	Planed Wood	0.012
		Unplaned Wood	0.013
Corrugated Polyethylene (PE) with smooth inner walls ^{a,b}			0.009-0.015
Corrugated Polyethylene (PE) with corrugated inner walls ^c			0.018-0.025
Polyvinyl Chloride (PVC) with smooth inner walls ^{d,e}			0.009-0.011

Pasted from <<http://www.lmnoeng.com/manningn.htm>>

Table 6.1 Cross-Sectional Relationships for Open-Channel Flow

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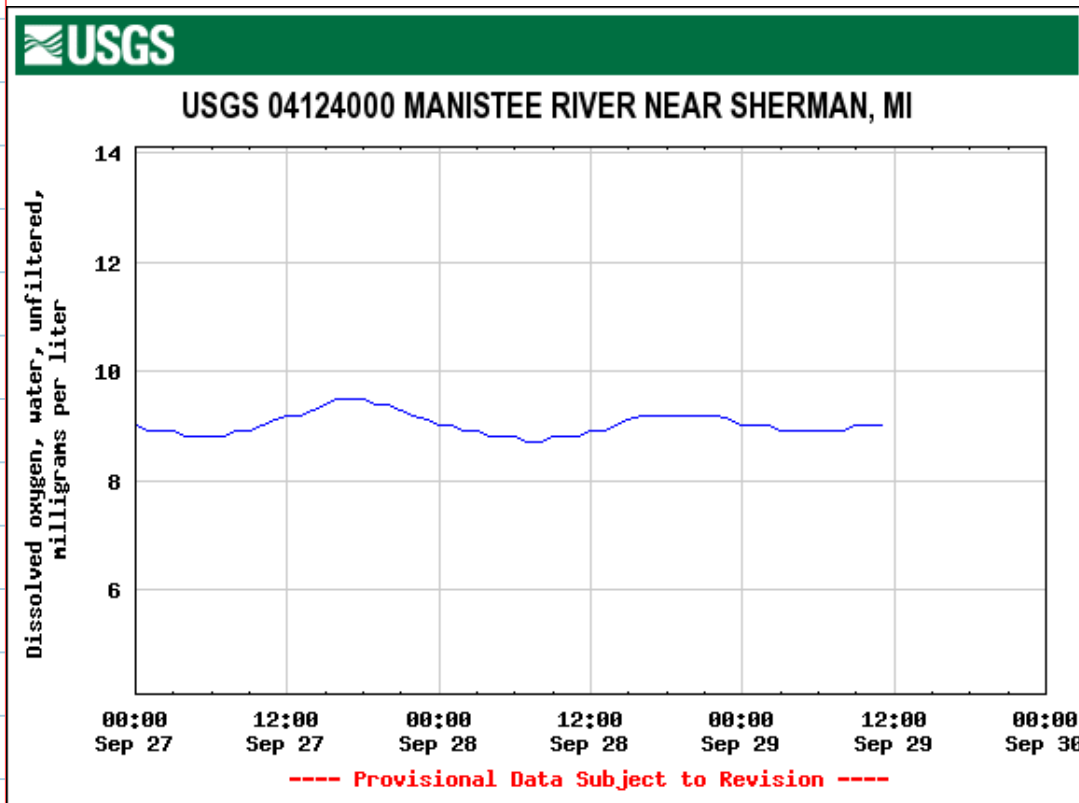
Section Type	Area (A)	Wetted perimeter (P)	Hydraulic Radius (R_h)	Top Width (T)	Hydraulic Depth (D)
Rectangular 	by	$b + 2y$	$\frac{by}{b + 2y}$	b	y
Trapezoidal 	$(b + my)y$	$b + 2y\sqrt{1 + m^2}$	$\frac{(b + my)y}{b + 2y\sqrt{1 + m^2}}$	$b + 2my$	$\frac{(b + my)y}{b + 2my}$
Triangular 	my^2	$2y\sqrt{1 + m^2}$	$\frac{my}{2\sqrt{1 + m^2}}$	$2my$	$\frac{y}{2}$
Circular (θ is in radians) 	$\frac{1}{8}(2\theta - \sin 2\theta)d_0^2$	θd_0	$\frac{1}{4}(1 - \frac{\sin 2\theta}{2\theta})d_0$	$(\sin \theta)d_0$ or $2\sqrt{y(d_0 - y)}$	$\frac{1}{8}\left(\frac{2\theta - \sin 2\theta}{\sin \theta}\right)d_0$

Source: V. T. Chow, *Open Channel Hydraulics* (New York: McGraw-Hill, 1959).

Dissolved Oxygen

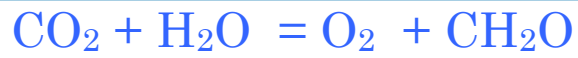
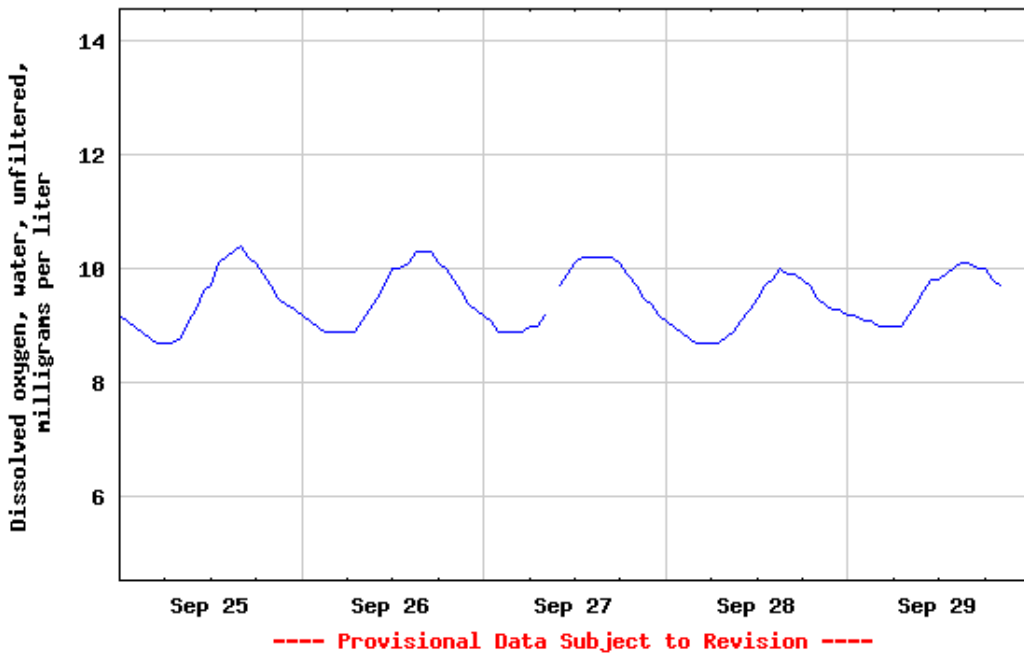
Monday, September 29, 2008
7:41 PM

Explain diurnal cycles of primary productivity, respiration, CO₂ and O₂



http://waterdata.usgs.gov/nwis/uv?cb_00060=on&cb_00300=on&format=gif_default&period=2&site_no=04124000

USGS 04136900 AU SABLE RIVER NEAR MC KINLEY, MI



Example

Monday, September 15, 2008
10:50 AM

- 4 - 2, p. 210 A Concrete sewer pipe 4 ft in diameter is laid so it has a drop in elevation of 1 ft per 1000 ft of length. If sewage (assume water properties) flows at a depth of 2 ft in the pipe, what will be the discharge?
-

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The Manning formula states:

$$V = \frac{k}{n} R_h^{\frac{2}{3}} \cdot S^{\frac{1}{2}}$$

where:

V is the cross-sectional average velocity (ft/s, m/s)

k is a conversion constant equal to 1.486 for U.S. customary units or 1.0 for SI units

n is the Manning coefficient of roughness (independent of units)

R_h is the hydraulic radius (ft, m)

S is the slope of the water surface or the linear hydraulic head loss (ft/ft, m/m) ($S = h_f / L$)

assume $n = 0.013$

```
slope = 1. / 1000; Print["Slope = ", slope]
```

```
Slope = 0.001
```

Strategy: The pipe is half full,
so this makes it easy to calculate the wetted area and wetted perimeter.

```
dia = 4.; area = Pi (dia / 2) ^2 / 2.  
perimeter = Pi (dia / 2)  
n = 0.013;  
Q = 1.49 / n area (area / perimeter) ^0.6667 Sqrt[slope]
```

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6.28319
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6.28319
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22.7731
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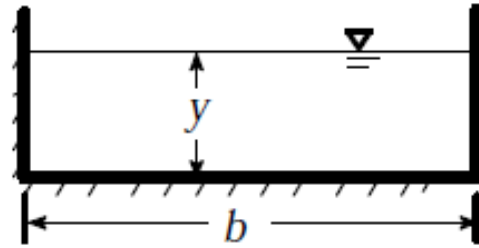
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6.3

Monday, September 15, 2008
10:53 AM

Example: Water flows uniformly in a rectangular channel of width b and depth y . Determine the *aspect ratio* b/y for the best hydraulic cross section.



$$A = by \text{ or } b = \frac{A}{y}$$

$$P = b + 2y$$

$$R_h = A/P = \frac{by}{(b + 2y)}$$

Uniform Flow Rectangular Channel

Let A be constant and let's minimize P . So

$$P = b + 2y \text{ or } P = \frac{A}{y} + 2y$$

Thus P varies only with y for a given A . Let's take dP/dy and set to zero to find minimum

$$\frac{dP}{dy} = -\frac{A}{y^2} + 2 = 0$$

so

$$\frac{A}{y^2} = 2$$

But $A = by$, so

$$\frac{by}{y^2} = 2 \text{ or } y = \frac{1}{2}b$$

S Thus best hydraulic cross-section for a rectangular channel occurs when the depth is one-half the width of the channel

for a constant area and slope, the shape with the greatest hydraulic radius has the most flow (is most efficient)

$$R = A/P = \text{flow area/wetted perimeter}$$

if we're keeping Area constant then we want the shortest wetted perimeter

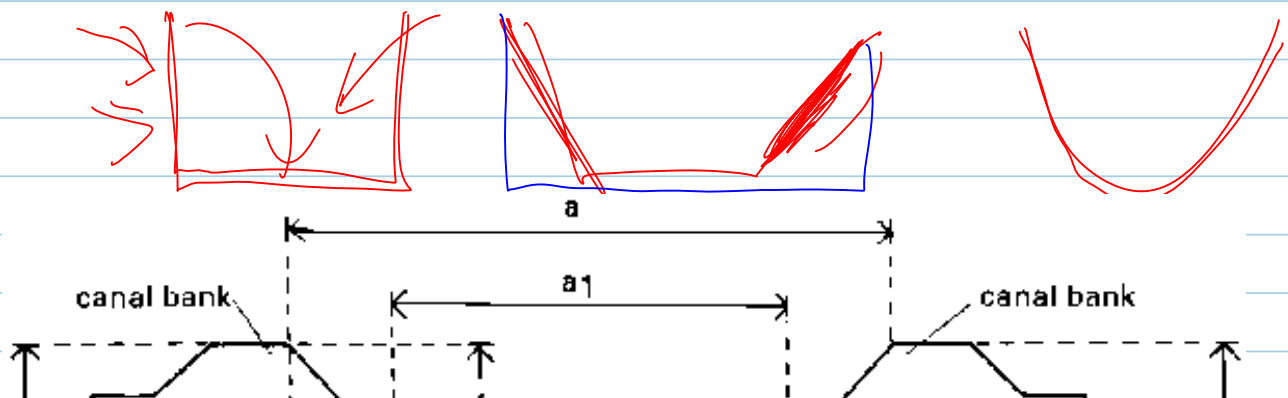
rectangular: $R =$

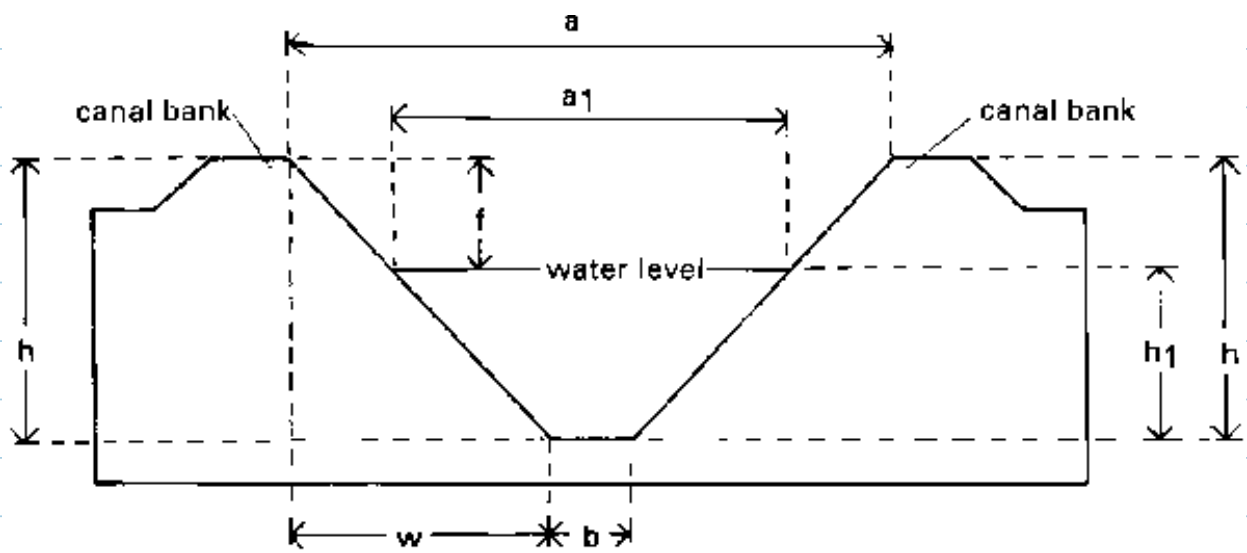
is most efficient as a half square

trapezoidal = most efficient is 60degree sides (half hexagon)

usually practicality and economics control and the trapezoidal channels tend to be least expensive because the concrete is stable and thus doesn't have to be strong and it is easy to build

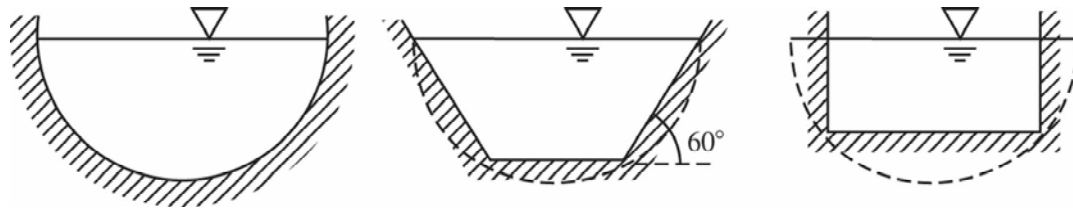
all designs require freeboard of 0.5 to several feet of freeboard





- a = top width of the canal
- a_1 = top width of the water level
- h = height of the canal
- h_1 = height or depth of the water in the canal
- b = bottom width of the canal
- $h:w$ = side slope of the canal
- f = free board ($= h - h_1$)

Figure 6.5 Hydraulically efficient sections



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6.4 Specific Energy

Wednesday, September 17, 2008
9:05 PM

Note: use my own notes to go over this lecture

Kinetic energy in open channel flow sometimes requires a correction factor to account for nonuniform velocity

velocity is greater near the surface and in the middle and so especially is V^2 . Given the square of velocity, it doesn't exactly average out

$\alpha(V^2/2g)$ where α ranges from 1.05 to 1.20

in simple analysis (all we will do in this class) α is taken as 1

given the free surface on top (air/atmosphere interface) the pressure head is taken as the depth

total head = $V^2/2g + \text{depth} + z$

Specific Energy is taken as the head measured with respect to the channel bottom in the section

$E = \text{specific energy} = V^2/2g + \text{depth}$

specific energy at three different flow rates in the same channel, each with multiple depths

$d \uparrow$

channel, each with multiple depths

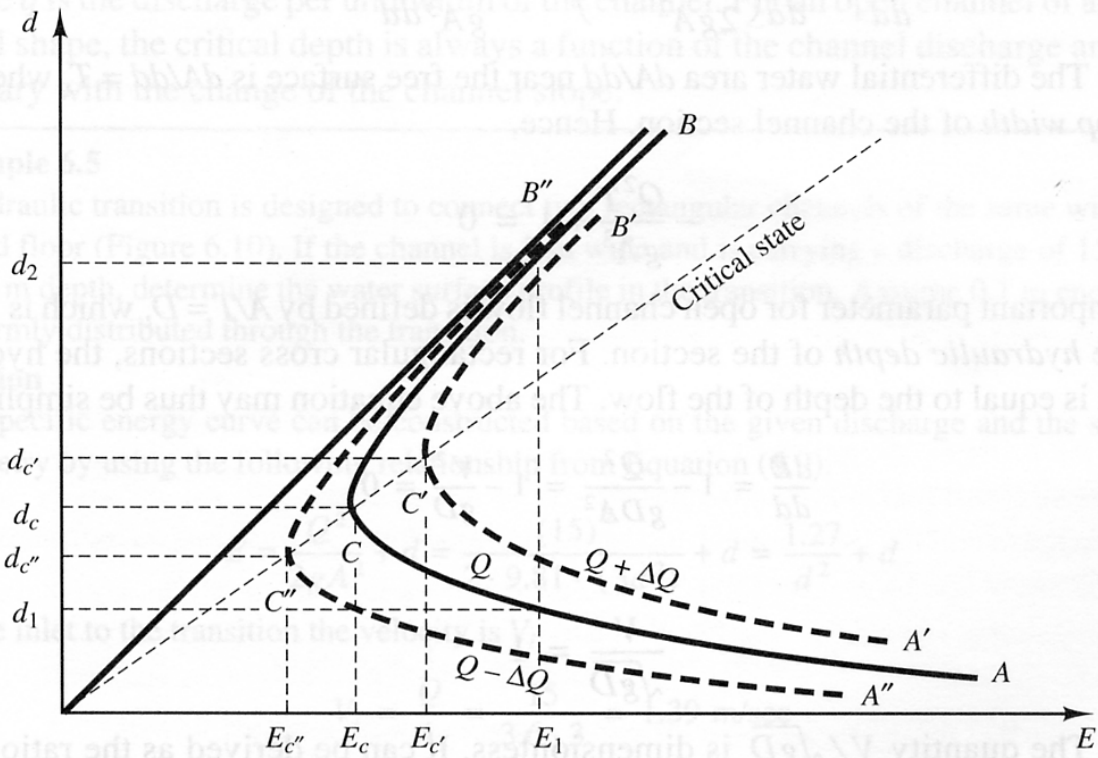


Figure 6.9 Specific energy curves of different discharges in a given open channel.

energy can be mostly in the depth or mostly in the velocity or split between, lowest energy is at critical flow

6.5 Hydraulic Jump

Wednesday, September 17, 2008
9:30 PM

6.6 Gradually Varied Flow

Wednesday, September 17, 2008
9:30 PM

Gradually Varied Flow

Monday, September 24, 2007
9:12 AM

Gradually varied flow differs from uniform flow and rapidly varied flow (hydraulic jumps) in that the change in water depth in the channel takes place very gradually with distance.

This is steady but nonuniform flow

computers can solve this problem, we will study the general trends

these can be categorized into a series of profiles (what we will do)

one can also solve for the change in water depth over distance

dd/dx = change in depth of water over distance =
function of slope and discharge

Channel properties are defined in terms of critical depth and normal depth, the normal depth is the depth given by the Manning Equation

horizontal and adverse channels (obvious in name)

steep is when normal depth is supercritical

mild is when normal depth is subcritical

critical is when normal depth is critical

Steep, Critical, Mild, Horizontal, Adverse (SCMHA)

Type I: dd/dx is positive, water is getting deeper, a backwater

Type II: dd/dx is negative, water is getting shallower, accelerating

Type III: dd/dx is positive such as slowing before a hydraulic jump or going from very supercritical to less supercritical

The equation for gradually varied flow

is (6.21), (6.22), and (6.23) into Eq

$$\frac{dd}{dx} = \frac{S_0 \left[1 - \left(\frac{d_n}{d} \right)^{10/3} \right]}{\left[1 - \left(\frac{d_c}{d} \right)^3 \right]}$$

is a partial differential equation for gradually varied flow

d is the depth so $dd/dx = 0$ means uniform flow at constant depth

Another form of the equation is:

Using the equation gives

$$\frac{dd}{dx} = \frac{\frac{dH}{dx} - \frac{dz}{dx}}{1 - \frac{Q^2 T}{gA^3}}$$

where H is total energy head

Flood

Tuesday, October 02, 2007
10:02 AM

Where is the flow sub and supercritical?

What is the Froude number?

What profiles?

note: profiles are complicated by changes in n as well as slope, not everything fits the ideal pattern, note change in Manning's n at end of concrete lining



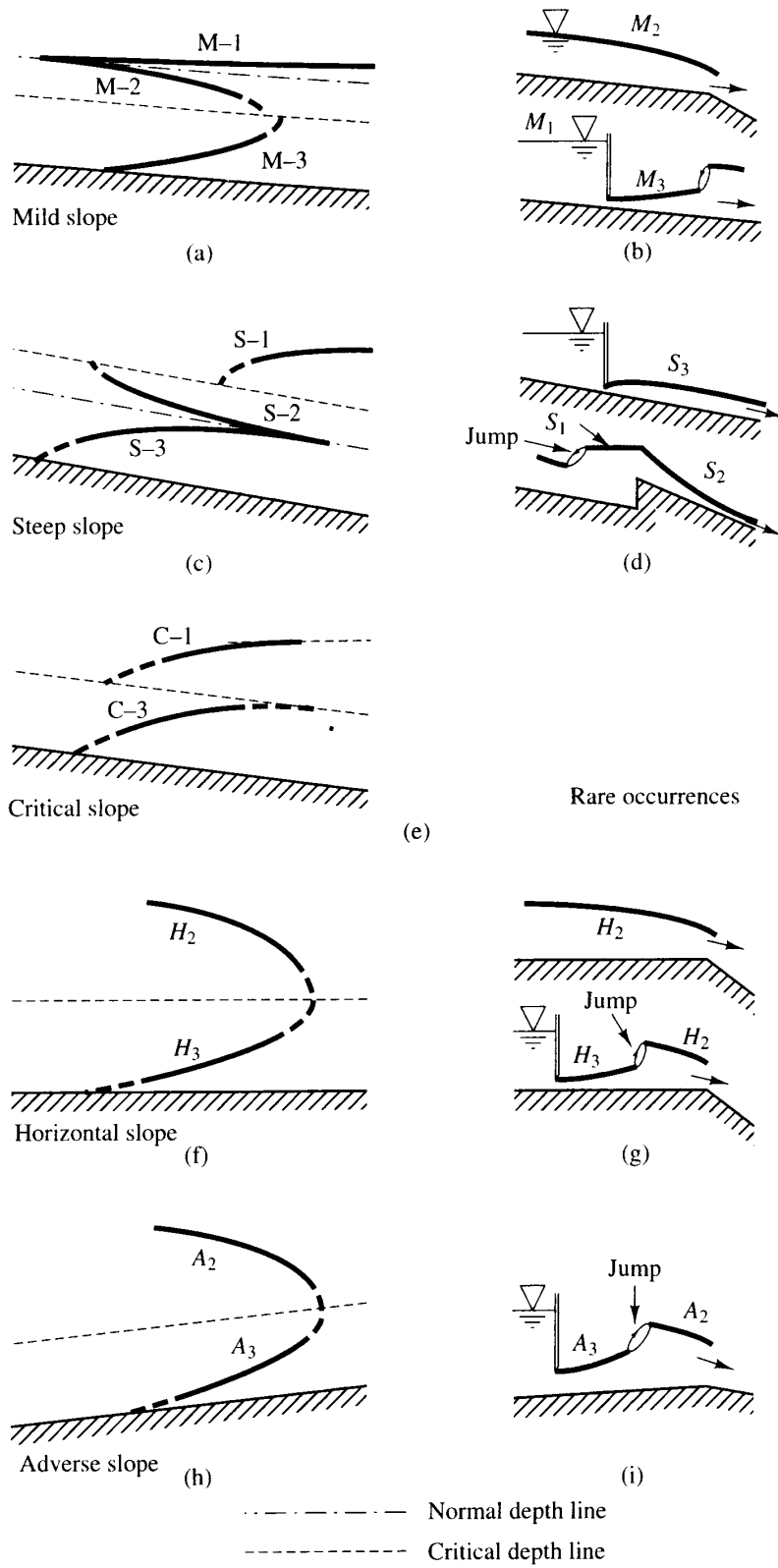
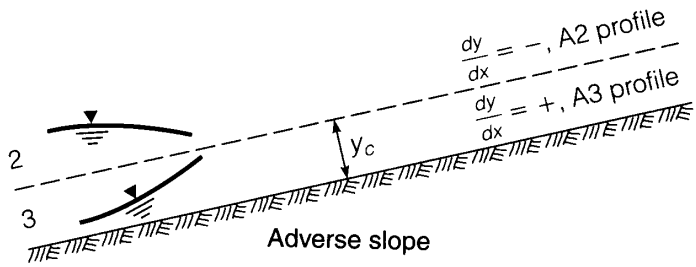
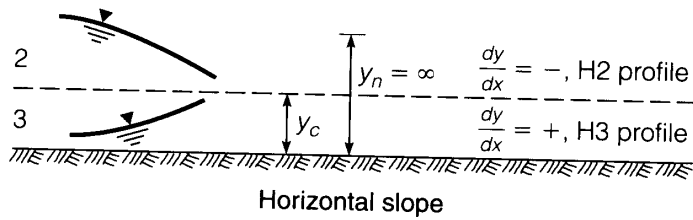
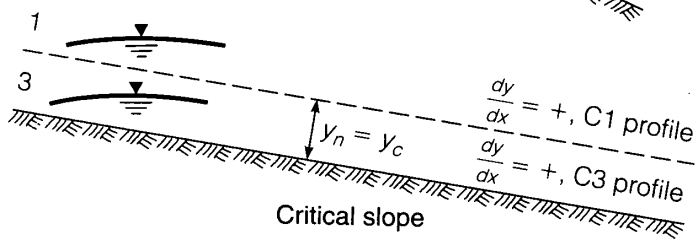
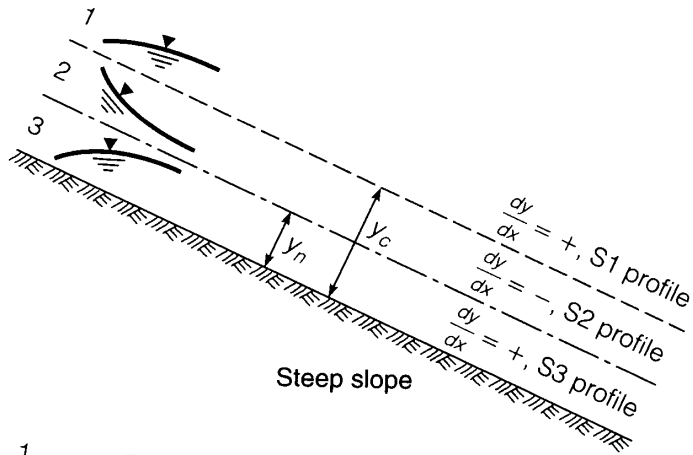
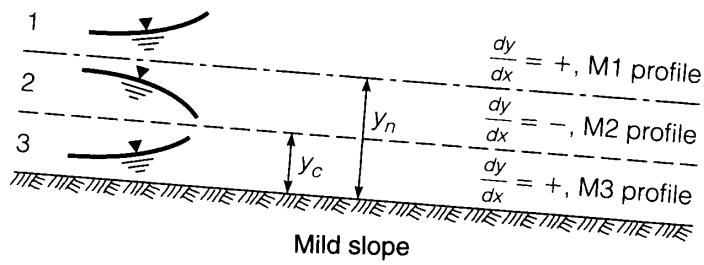
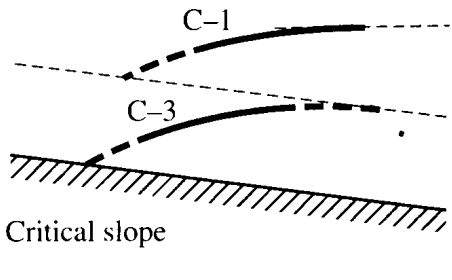
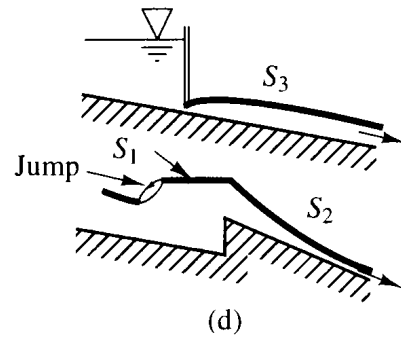
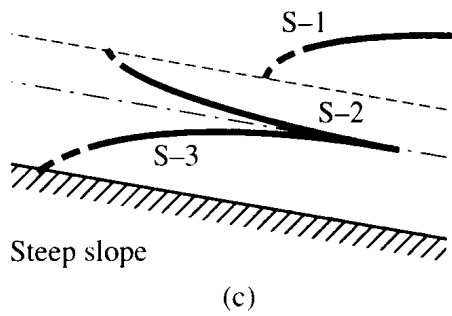
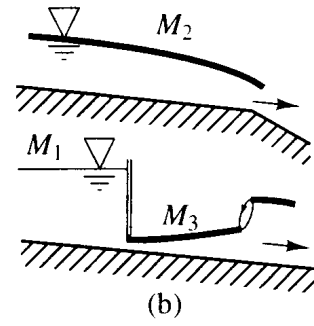
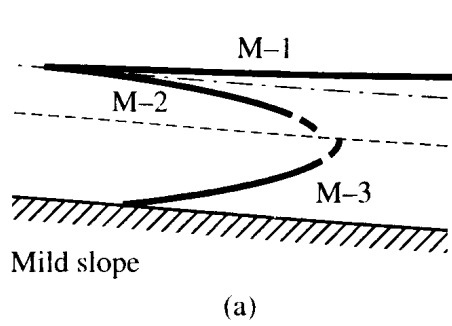


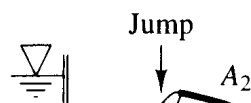
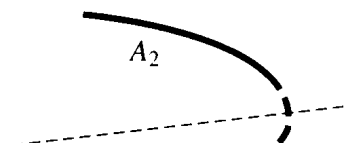
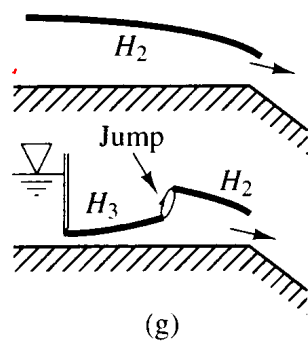
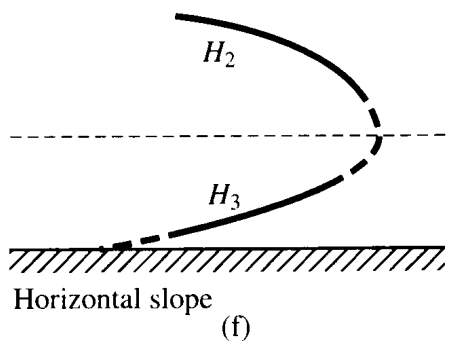
Figure 6.12 Types of gradually varied flow.



c. 6.7 Classifications of Gradually Varied Flow



Rare occurrences



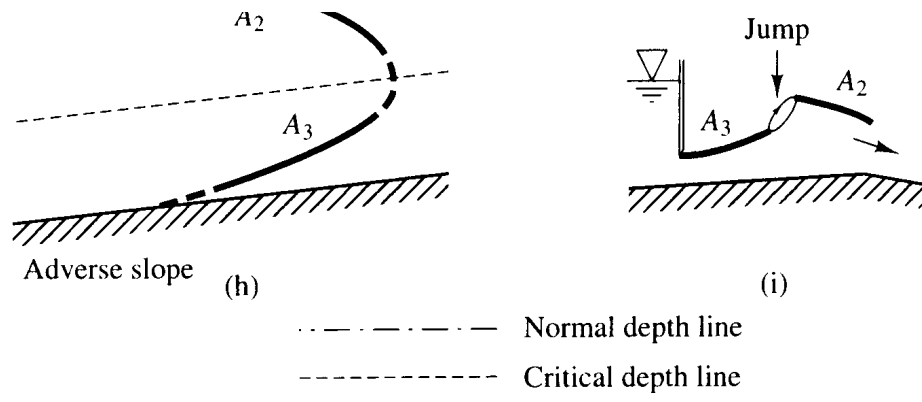
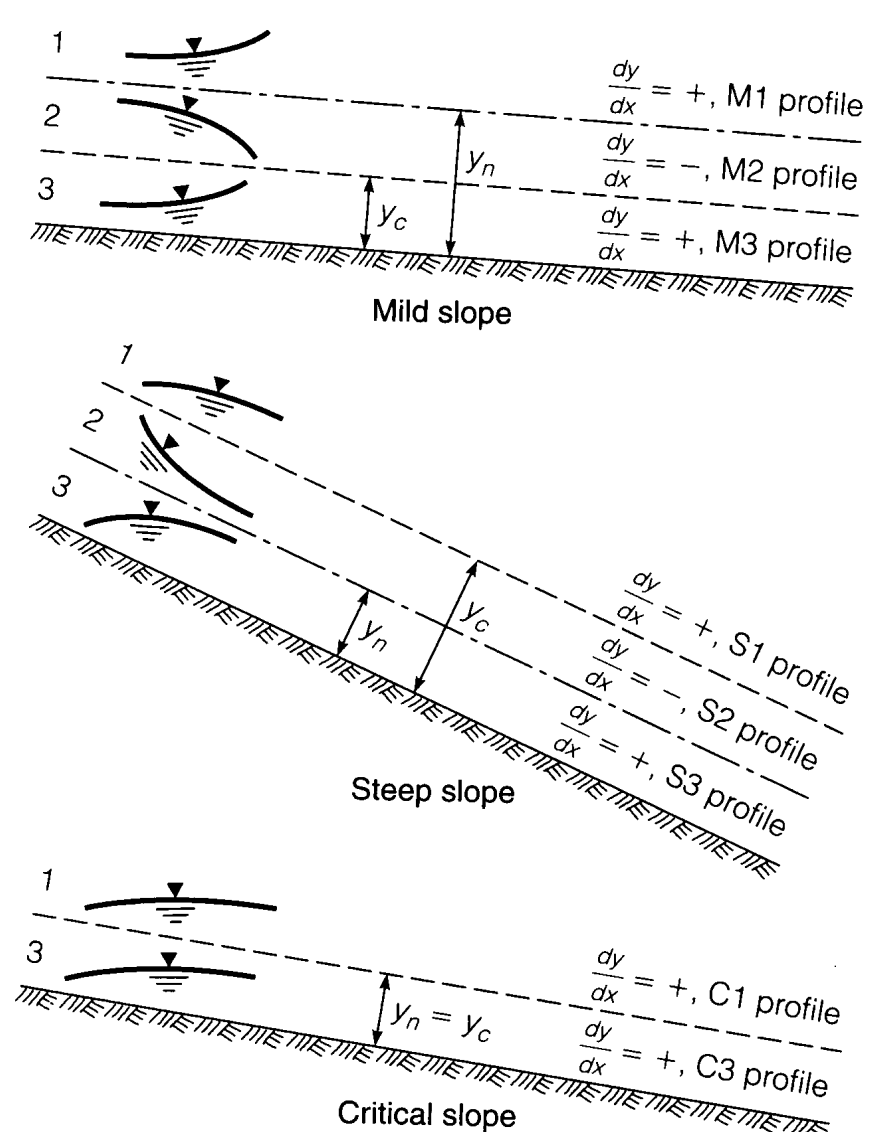
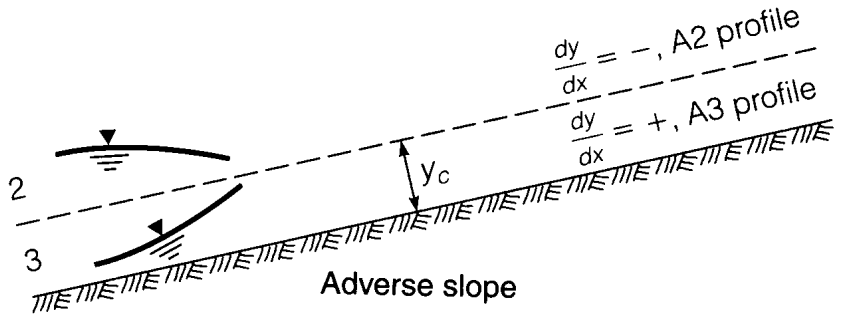
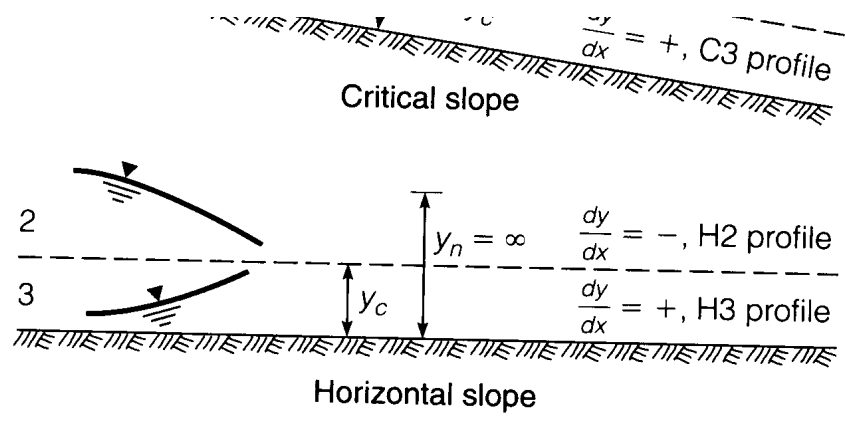


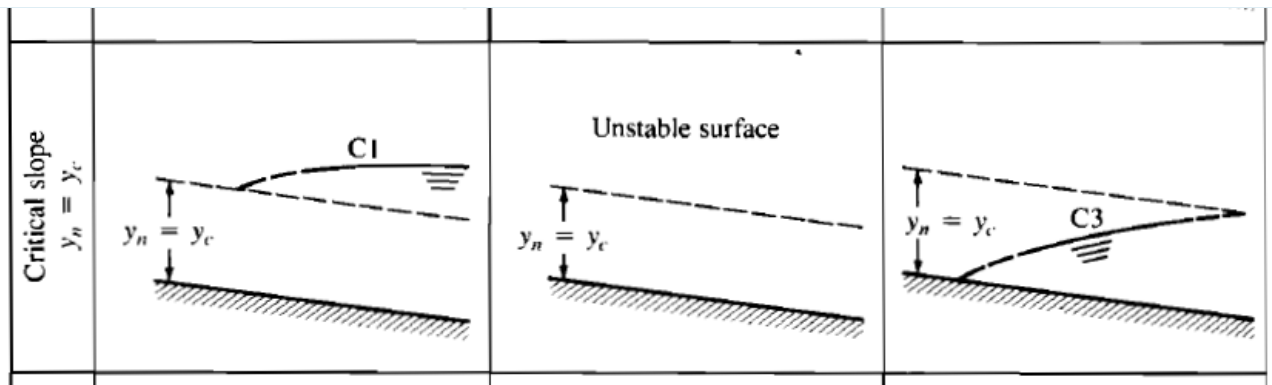
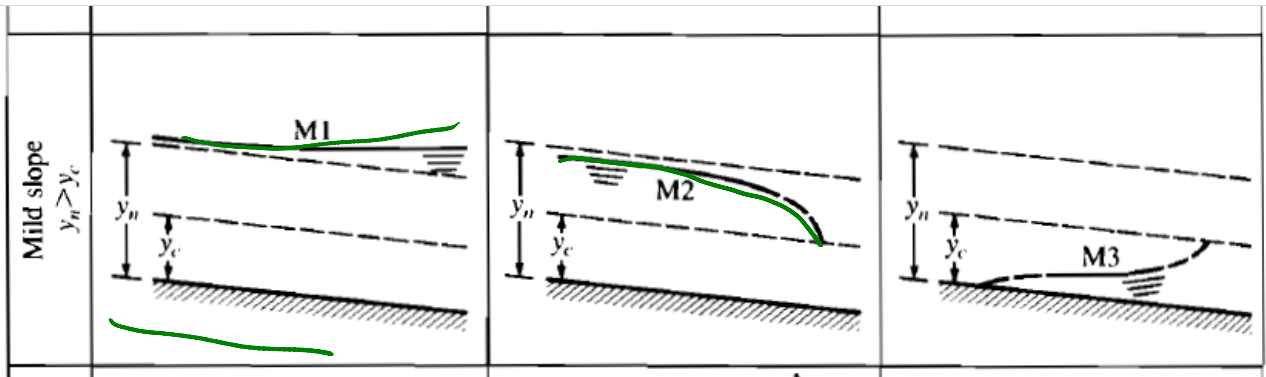
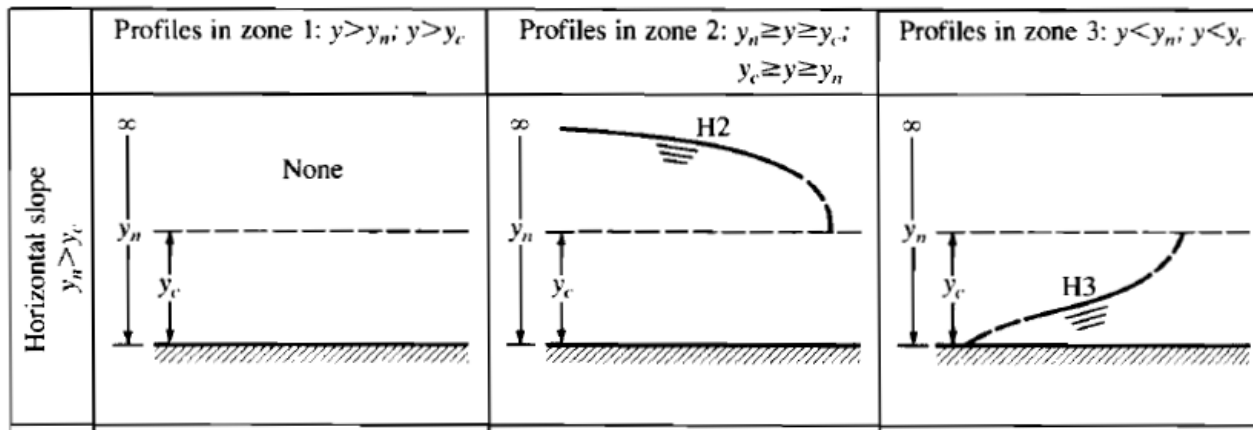
Figure 6.12 Types of gradually varied flow.

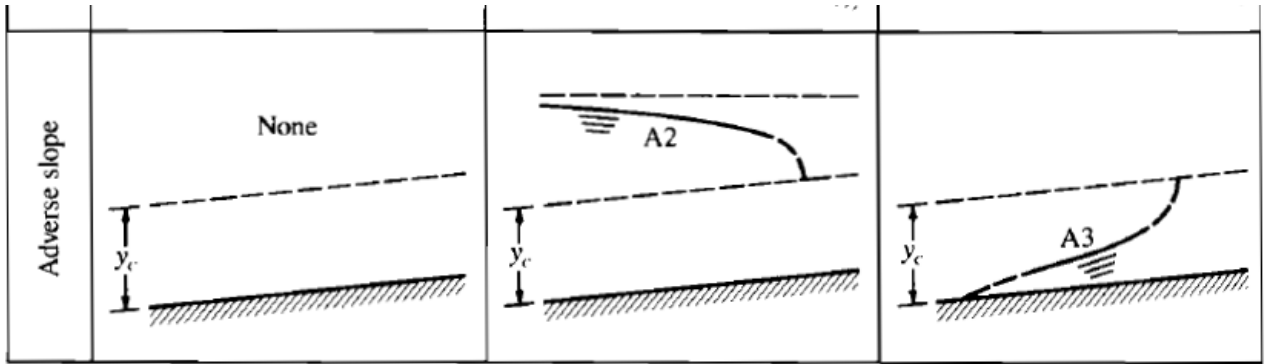
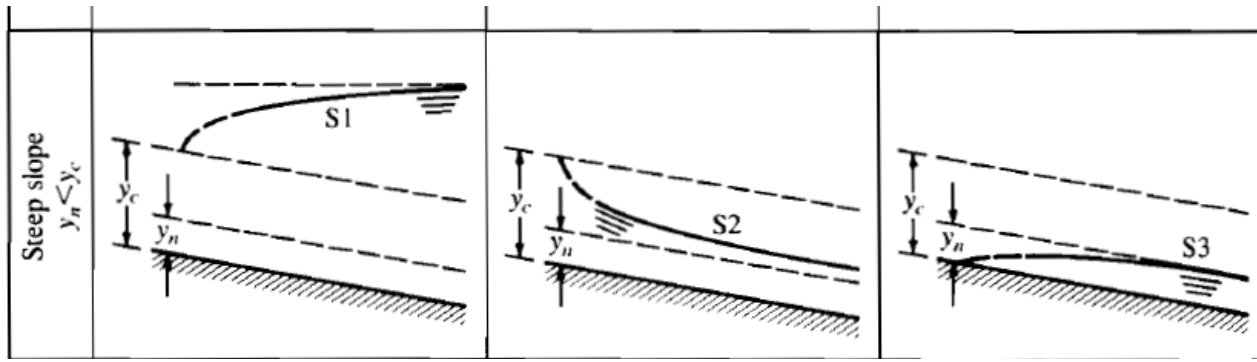




Surface Profiles

Tuesday, September 25, 2007
8:12 AM





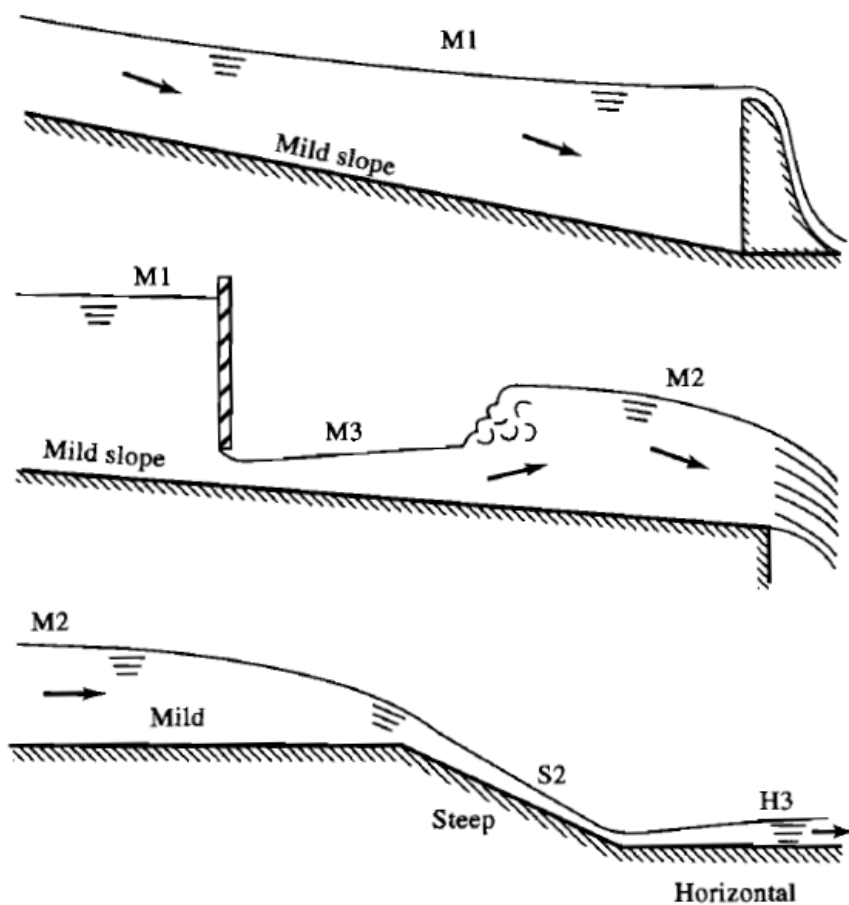


Figure 4-30 Water surface profiles associated with flow behind a dam, flow under a sluice gate, and flow in a channel with a change in grade

An example of simple and clear design standards

<http://www.pub.gov.sg/downloads/DR7.aspx>

Design
**Cons
idera
tions**

7.3. Minimum Velocity and Dry Weather Flow 1

The velocity of flow in a drain shall not be lower than 1.0 m/s for self-cleansing action to take place. However, the flow rate during dry weather may fall to a low level where this minimum velocity cannot be achieved. The problem can be solved by introducing a small channel in the drain to confine the dry weather flow to a smaller flow section. The dimensions of such a dry weather flow channel depend on the width of the drain and are tabulated in [Drawing No. 1](#).

7.3. Maximum Velocity 2

The velocity of flow in a drain shall not be too

great to cause excessive scouring or hydraulic jumps. Hence the velocity of flow in a concrete-lined drain shall be limited to a maximum of 3.0 m/s or below the critical velocity, whichever is lower. For an earth stream, the maximum velocity shall be limited to 1.5 m/s. Further limitation of the maximum velocity shall be complied with when specified by the Public Utilities Board.

7.3. Sub-critical Flow

3

Drains are designed to carry sub-critical flows. Critical state of flow exists when the Froude Number is equal to one. An open channel flow at or near the critical state shall be avoided as under such a condition the water surface is unstable and wavy. In order to secure greater flow efficiency, channel flow shall be designed so that the Froude Number shall fall within the range from 0.8 decreasing to such minimum value as to achieve a practical flow depth and permissible flow velocity.

7.3. Freeboard

4

Freeboard refers to the depth from the top of the drain (cope/bank) to the top of the water surface in the drain at design flow condition. Sufficient freeboard shall be provided to prevent waves or fluctuation of the water surface from overflowing the cope/bank. Generally, a depth of freeboard equivalent to 15% of the depth of the drain is required.

Pasted from <<http://www.pub.gov.sg/downloads/DR7.aspx>>

6.7 Classification

Wednesday, September 17, 2008
9:31 PM

6.8 Computation of Profiles

Wednesday, September 17, 2008
9:31 PM