

CE 3121

Engineering Hydraulics

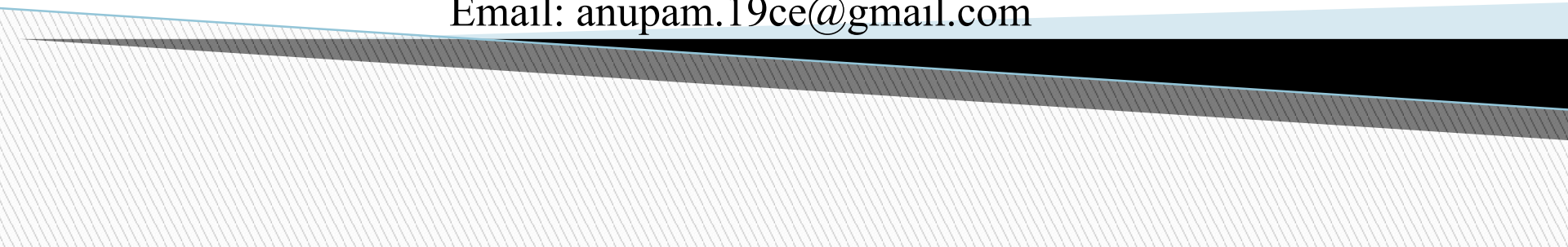
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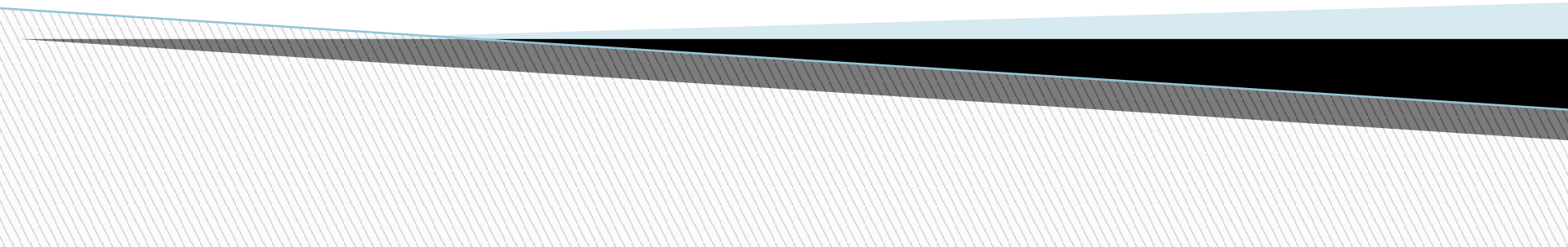
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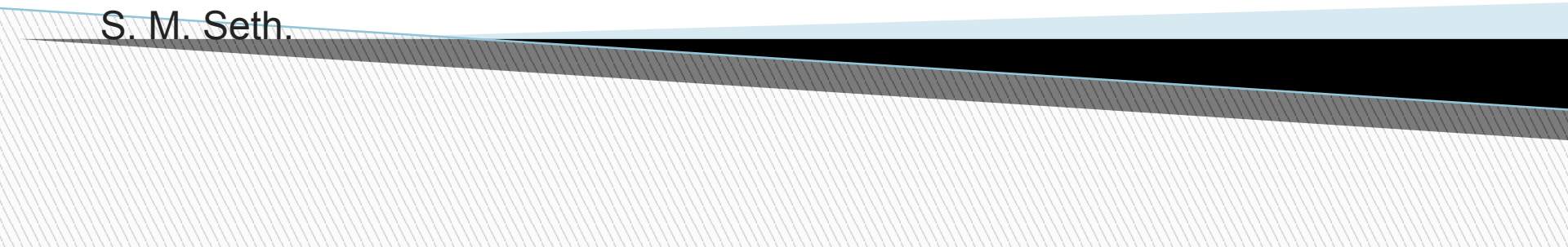
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Course Contents

- Theory and analysis of gradually varied flow
 - Computation of flow profiles
 - Hydraulic jump
 - Stilling basin
 - Impact of water jet
 - Principles of hydraulic machines: pumps-Reciprocating and Centrifugal pump
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Reference Books

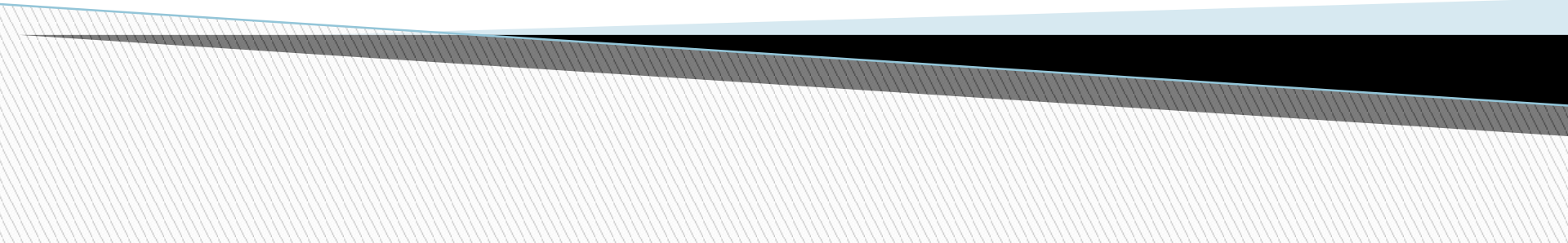
- Open Channel Flow Hydraulics – Ven Te Chow
 - A textbook of Hydraulics, Fluid Mechanics and Hydraulic Machines – R. S. Khurmi
 - A textbook of Fluid Mechanics and Hydraulic Machines- R. K. Bansal
 - Hydraulics and Fluid Mechanics including Hydraulics Machines – P. N. Modi and S. M. Seth.
- 

Open Channel Flow

Open Channel Flow is defined as **fluid flow** with a free surface **open** to the atmosphere.

Examples: streams, rivers and culverts not flowing full.

Open channel flow assumes that the pressure at the surface is **constant** and the **hydraulic grade line** is at the surface of the fluid.



Classifications of Open Channel Flow

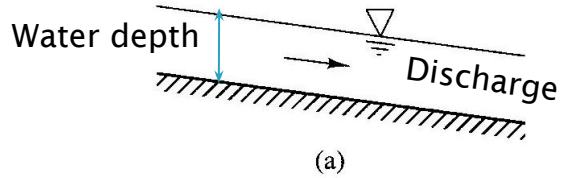
Classification based on the time criterion:

1. **Steady Flow** (time independent)
(discharge and water depth do not change with time)
2. **Unsteady Flow** (time dependent)
(discharge and water depth at any section change with time)

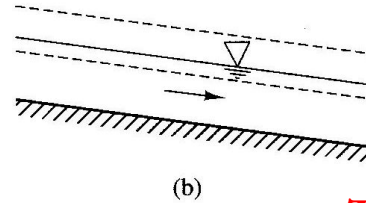
Classification based on the space criterion:

1. **Uniform flow** (are mostly steady)
(discharge and water depth remains the same at every section in the channel)
2. **Non-uniform Flow/Varied flow**
(discharge and water depth change at any section in the channel)

a) Uniform flow are mostly steady

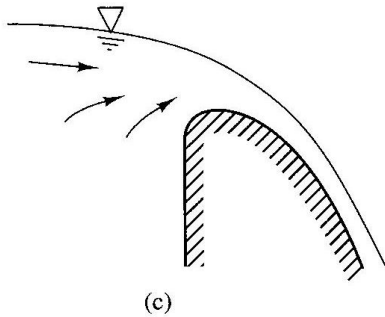


b) Unsteady uniform flows are very rare in nature

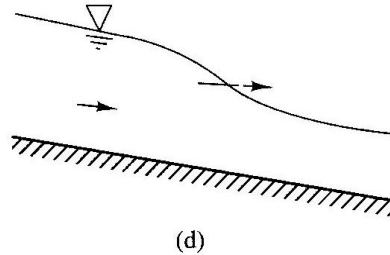


Tidal Surge=জলোচ্ছাস

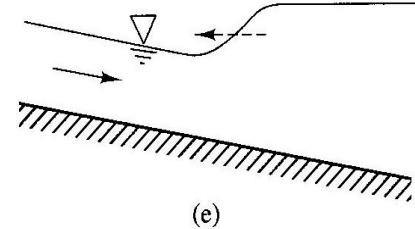
c) Steady varied flow
(over a spillway crest)



d) Unsteady varied flow (flood wave)



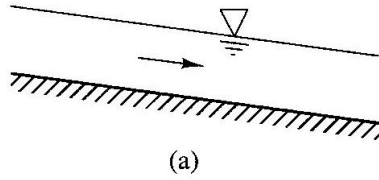
e) Unsteady varied flow (tidal surge)



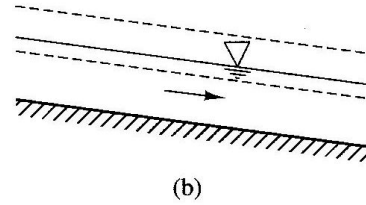
Non-uniform flow is also called **varied flow** (the flow in which the water depth and or discharge change along the length of the channel), it can be further classified as:

- ▣ **Gradually varied flow (GVF):** where the depth of the flow changes gradually along the length of the channel.
- ▣ **Rapidly varied flow (RVF):** where the depth of flow changes suddenly over a small length of the channel.

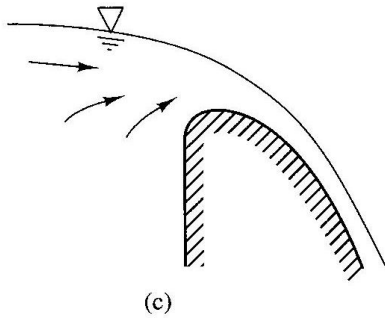
a) Uniform flow are mostly steady



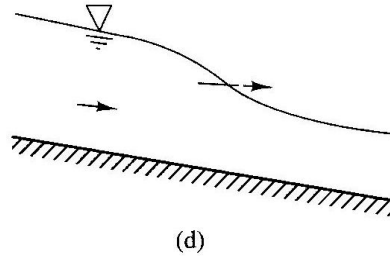
b) Unsteady uniform flows are very rare in nature



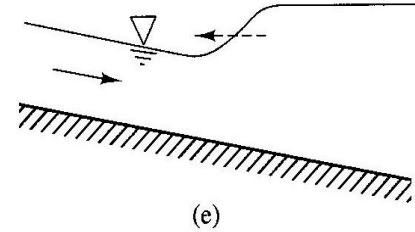
c) Steady varied flow (over a spillway crest)



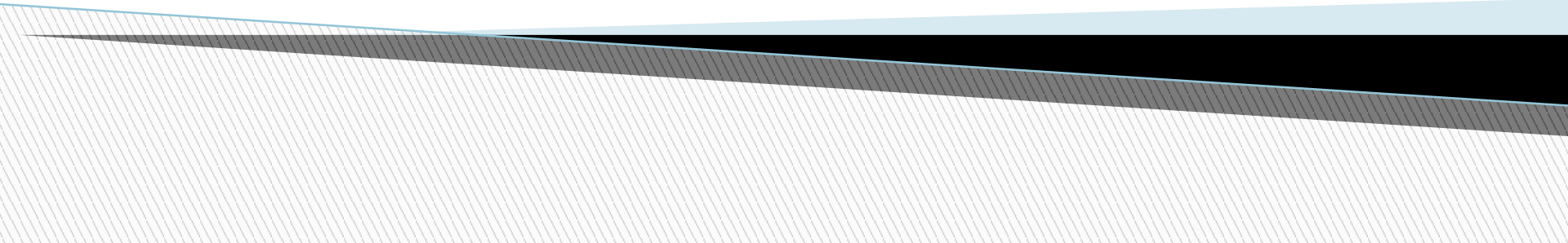
d) Unsteady varied flow (flood wave)



e) Unsteady varied flow (tidal surge)



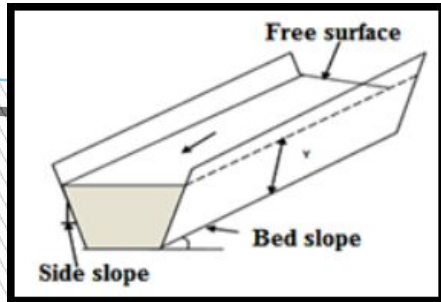
Gradually-Varied Flow in Open Channels



Gradually-Varied Flow

Gradually-Varied Flow: A steady non-uniform flow in a prismatic channel with gradual changes in its water-surface elevation is named as gradually-varied flow (GVF).

Gradually varied flow (GVF) where the depth of the flow changes gradually along the length of the channel.



Prismatic Channel

Dynamic Equation of Gradually Varied Flow

Objective: To get the relationship between the water surface slope and other characteristics of flow.

The following assumptions are made in the derivation of the equation

1. The flow is steady.
2. The streamlines are practically parallel (true when the variation in depth along the direction of flow is very gradual). Thus the hydrostatic distribution of pressure is assumed over the section.
3. The loss of head at any section, due to friction, is equal to that in the corresponding uniform flow with the same depth and flow characteristics. (Manning's formula may be used to calculate the slope of the energy line)
4. The slope of the channel is small.
5. The channel is prismatic.
6. The velocity distribution across the section is fixed.
7. The roughness coefficient is constant in the reach.

Consider the profile of a gradually varied flow in a small length dx of an open channel as shown in the figure below.

The total head (H) at any section is given by:

$$H = Z + y + \frac{V^2}{2g}$$

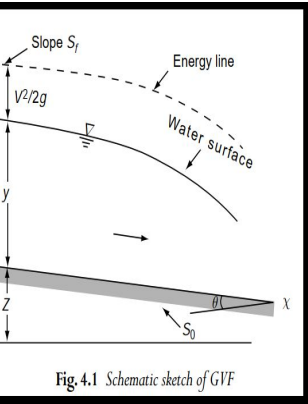


Fig. 4.1 Schematic sketch of GVF

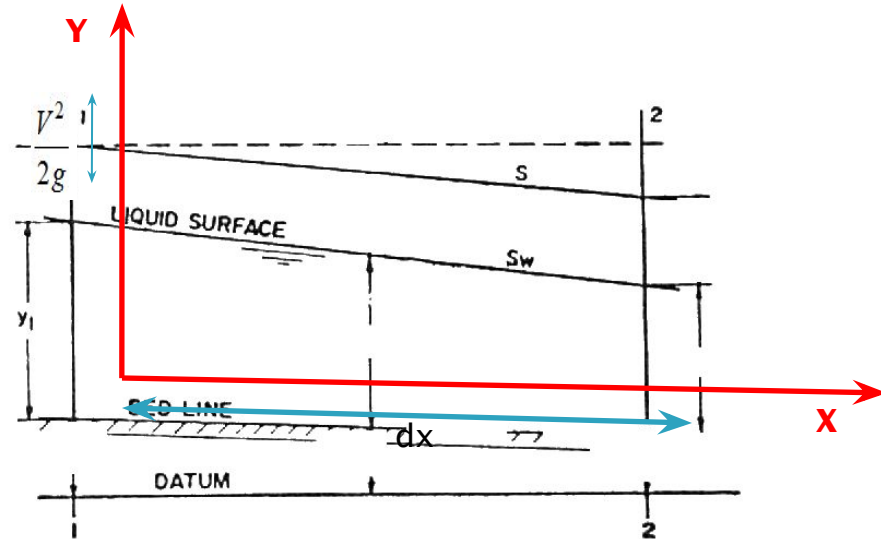


Figure From:
K. Subramanya

Taking x -axis along the bed of the channel and differentiating the equation with respect to x :

$$\frac{dH}{dx} = \frac{dZ}{dx} + \frac{dy}{dx} + \frac{d}{dx} \left(\frac{V^2}{2g} \right)$$

- dH/dx = the slope of the energy line (S_e).
- dZ/dx = the bed slope (S_0).

Therefore,

$$-S_e = -S_0 + \frac{dy}{dx} + \frac{d}{dx} \left(\frac{V^2}{2g} \right)$$

Multiplying the velocity term by dy/dy and transposing, we get

$$\frac{dy}{dx} + \frac{dy}{dy} \frac{d}{dx} \left(\frac{V^2}{2g} \right) = S_0 - S_e \quad \text{or} \quad \frac{dy}{dx} \left[1 + \frac{d}{dy} \left(\frac{V^2}{2g} \right) \right] = S_0 - S_e$$

$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 + \frac{d}{dy} \left(\frac{V^2}{2g} \right)}$$

This Equation is known as **the dynamic equation of gradually varied flow**. It gives the variation of depth (y) with respect to the distance along the bottom of the channel (x).

Gradually-Varied Flow

Derive the Basic Differential Equation for the Gradually-Varied Flow Water Surface Profile:

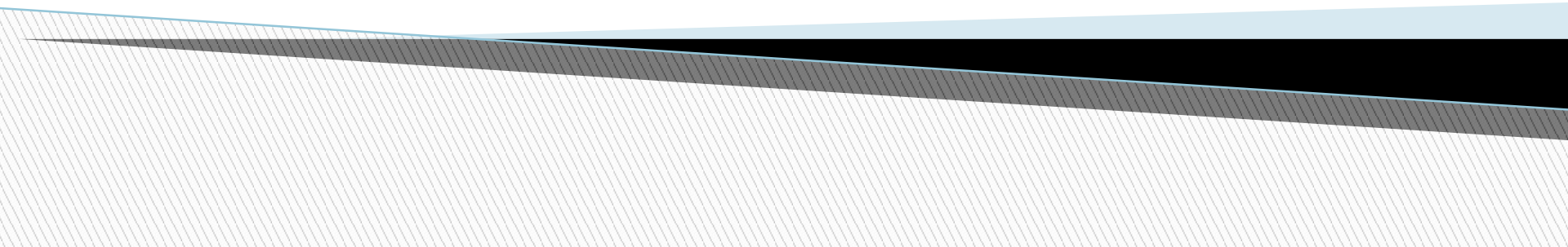
$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2}$$

dy/dx gives the variation of water depth along the channel in the flow direction.

S_0 = Channel bed slope for uniform flow depth y_0

S_e = Energy slope

Fr = Froude number



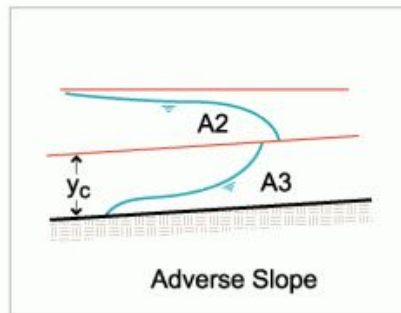
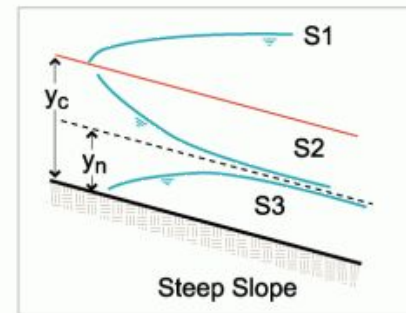
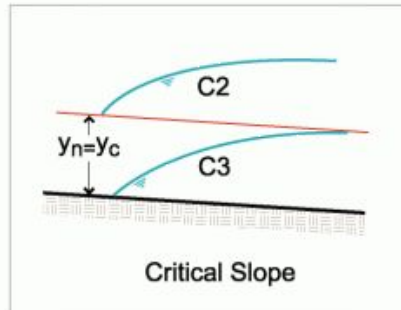
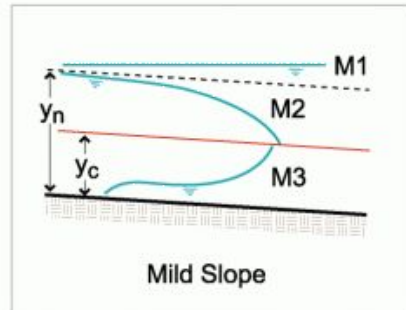
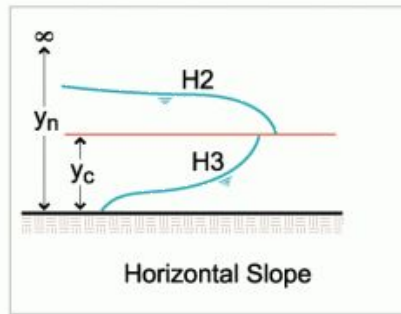
Gradually-Varied Flow

$$\frac{dy}{dx} = \frac{S_o - S_e}{1 + \frac{d}{dy} \left(\frac{V^2}{2g} \right)}$$

$$\frac{d}{dy} \left(\frac{V^2}{2g} \right) = \frac{Q^2}{2g} \frac{d}{dy} (A^{-2}) = - \frac{Q^2}{gA^3} \frac{dA}{dy} = - \frac{Q^2 T}{gA^3} = -F_r^2$$

$$\frac{dy}{dx} = \frac{S_o - S_e}{1 - F_r^2}$$

Water Surface Profiles of Gradually Varied Flow



Gradually-Varied Flow

Classification of Flow Surface Profiles

For a given channel with a known $Q = \text{Discharge}$, $n = \text{Manning coefficient}$, and $S_0 = \text{Channel bed slope}$, $y_c = \text{critical water depth}$ and $y_0 = \text{Uniform flow depth}$ can be computed. There are three possible relations between y_0 and y_c as 1) $y_0 > y_c$, 2) $y_0 < y_c$, 3) $y_0 = y_c$.

For horizontal ($S_0 = 0$), and adverse slope ($S_0 < 0$) channels,

$$Q = A \frac{1}{n} R^{2/3} S_0^{1/2}$$

Horizontal channel, $S_0 = 0 \rightarrow Q = 0$,

Adverse channel, $S_0 < 0$, Q cannot be computed,

For horizontal and adverse slope channels, uniform flow depth y_0 does not exist.

Gradually-Varied Flow

Classification of Flow Surface Profiles

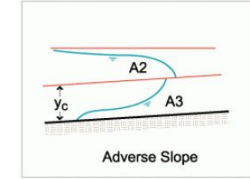
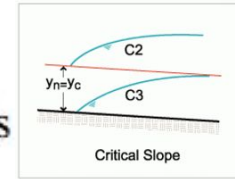
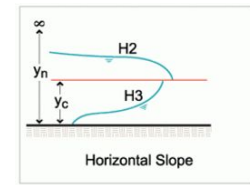
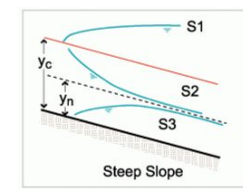
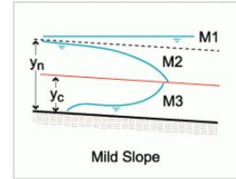
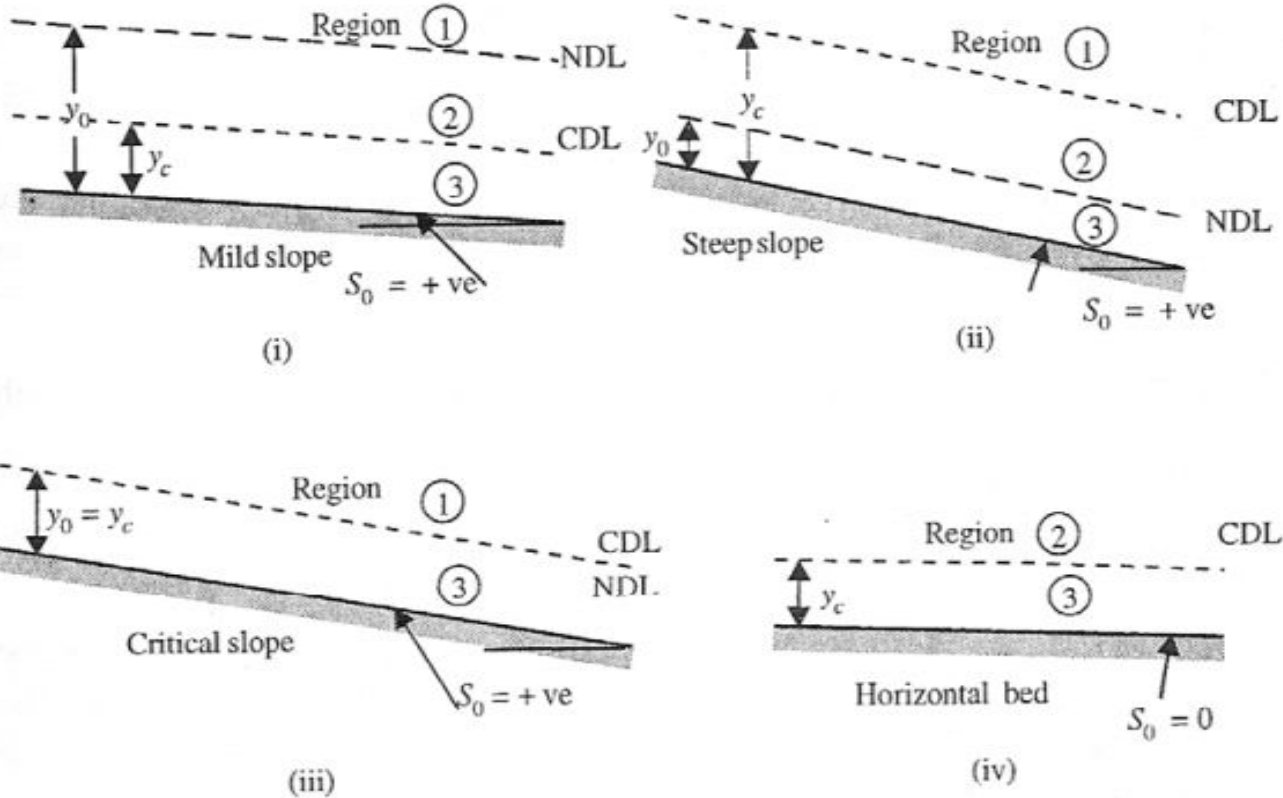


Table 6.1. Classification of channels

Number	Channel category	Symbol	Characteristic condition	Remark
1	Mild slope	M	$y_0 > y_c$	Subcritical flow at normal depth
2	Steep slope	S	$y_c > y_0$	Supercritical flow at normal depth
3	Critical slope	C	$y_c = y_0$	Critical flow at normal depth
4	Horizontal bed	H	$S_0 = 0$	Cannot sustain uniform flow
5	Adverse slope	A	$S_0 < 0$	Cannot sustain uniform flow

Gradually-Varied Flow



Gradually-Varied Flow

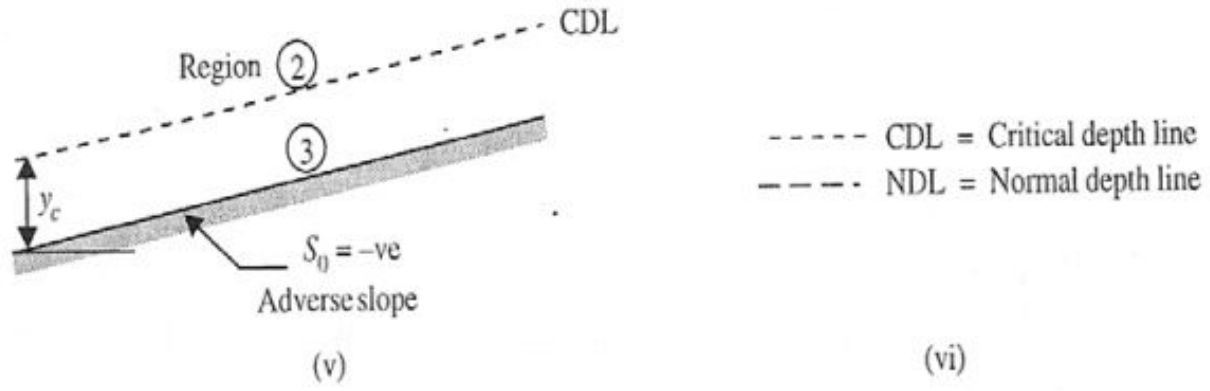


Figure 6.2. Regions of flow profiles

Gradually-Varied Flow

For a given Q , n , and S_0 at a channel,

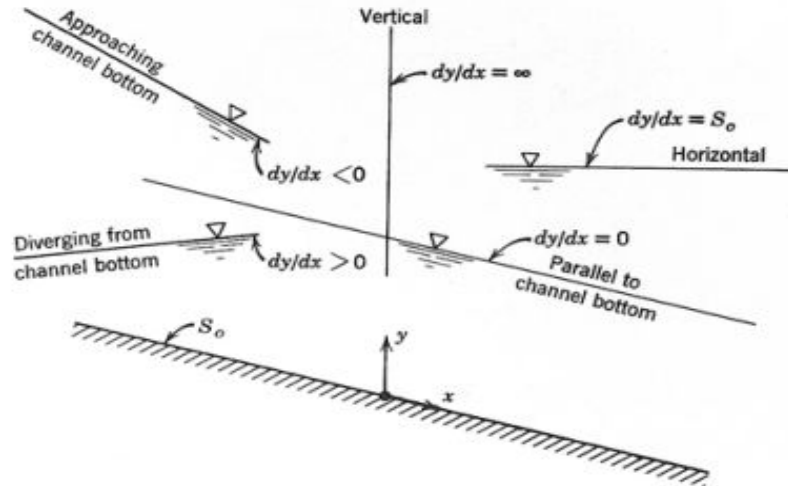
y_0 = Uniform flow depth,

y_c = Critical flow depth,

y = Non-uniform flow depth.

The depth y is measured vertically from the channel bottom, the slope of the water surface dy/dx is relative to this channel bottom. Fig. (6.3) is basic to the prediction of surface profiles from analysis of Equ. (6.3).

$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2}$$



Gradually-Varied Flow

To assist in the determination of flow profiles in various regions, the behavior of dy/dx at certain key depths is noted by studying Equ. (6.3) as follows:

$$y > y_c \rightarrow F_r < 1$$

$$y = y_c \rightarrow F_r = 1$$

$$y < y_c \rightarrow F_r > 1$$

$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2}$$

And also,

$$y > y_0 \rightarrow S_e < S_0$$

$$y = y_0 \rightarrow S_e = S_0$$

$$y < y_0 \rightarrow S_e > S_0$$

Gradually-Varied Flow

1. As $y \rightarrow y_0$, $V \rightarrow V_0$, $S_e = S_0$

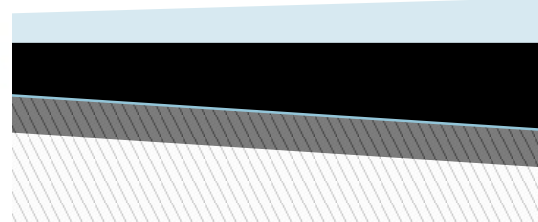
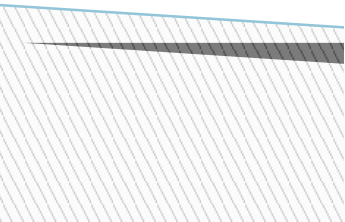
$$\lim_{y \rightarrow y_0} \frac{dy}{dx} = \frac{S_0 - S_0}{1 - F_r^2} = \frac{0}{\text{cons}} = 0$$

The water surface approaches the normal depth asymptotically.

2. As $y \rightarrow y_c$, $F_r^2 = 1$, $1 - F_r^2 = 0$,

$$\lim_{y \rightarrow y_c} \frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2} = \frac{S_0 - S_e}{0} = \infty$$

The water surface meets the critical depth line vertically.

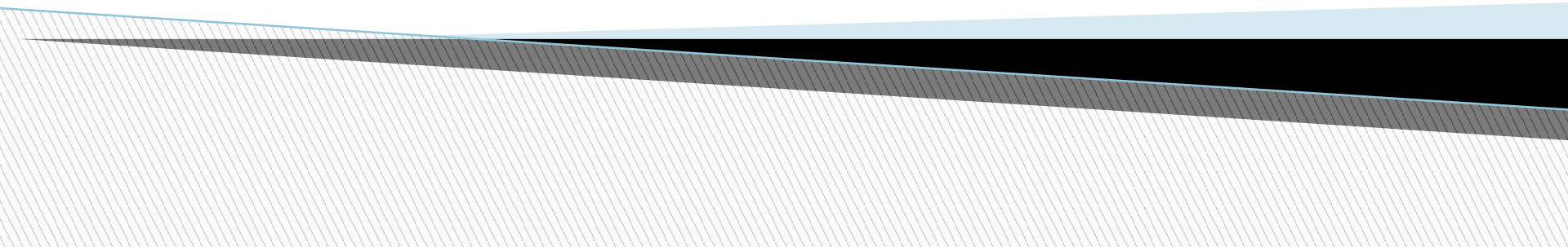


Gradually-Varied Flow

3. As $y \rightarrow \infty$, $V = 0 \rightarrow F_r = 0 \rightarrow S_e \rightarrow 0$

$$\lim_{y \rightarrow \infty} \frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2} = \frac{S_0}{1} = S_0$$

The water surface meets a very large depth as a horizontal asymptote.

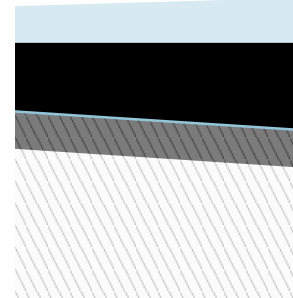


Gradually-Varied Flow

Based on this information, the various possible gradually varied flow profiles are grouped into twelve types (Table 6.2).

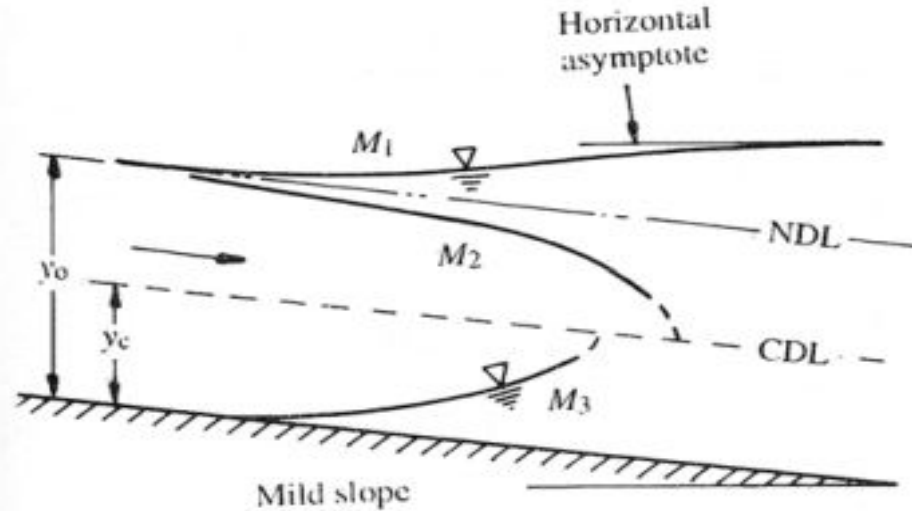
Table 6.2. Gradually Varied Flow profiles

Channel	Region	Condition	Type
Mild slope	1	$y > y_0 > y_c$	M_1
	2	$y_0 > y > y_c$	M_2
	3	$y_0 > y_c > y$	M_3
Steep slope	1	$y > y_c > y_0$	S_1
	2	$y_c > y > y_0$	S_2
	3	$y_c > y_0 > y$	S_3
Critical slope	1	$y > y_0 = y_c$	C_1
	3	$y < y_0 = y_c$	C_3
Horizontal bed	2	$y > y_c$	H_2
	3	$y < y_c$	H_3
Adverse slope	2	$y > y_c$	A_2
	3	$y < y_c$	A_3



Gradually-Varied Flow

M – Curves



Gradually-Varied Flow

a) M_1 – Curve

Water surface will be in Region 1 for a mild slope channel and the flow is obviously subcritical.

$$y > y_0 > y_c$$

$$S_e < S_0 \rightarrow \text{Mild slope channel}$$

$$y_0 > y_c \rightarrow \text{Subcritical flow}$$

$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2}$$

$$F_r < 1 \rightarrow \text{Subcritical flow} \rightarrow (1 - F_r^2) > 0$$

$$y > y_0 \rightarrow S_e < S_0$$

$$\frac{dy}{dx} = \frac{+}{+} > 0 \quad (\text{Water depth will increase in the flow direction})$$

$$y > y_c \rightarrow F_r < 1$$

$$y = y_c \rightarrow F_r = 1$$

$$y < y_c \rightarrow F_r > 1$$

$$y > y_0 \rightarrow S_e < S_0$$

$$y = y_0 \rightarrow S_e = S_0$$

$$y < y_0 \rightarrow S_e > S_0$$

Gradually-Varied Flow

The most common of all GVF profiles is the M_1 type, which is a subcritical flow condition. Obstructions to flow, such as weirs, dams, control structures and natural features, such as bends, produce M_1 backwater curves (Fig. 6.5). These extend to several kilometers upstream before merging with the normal depth.

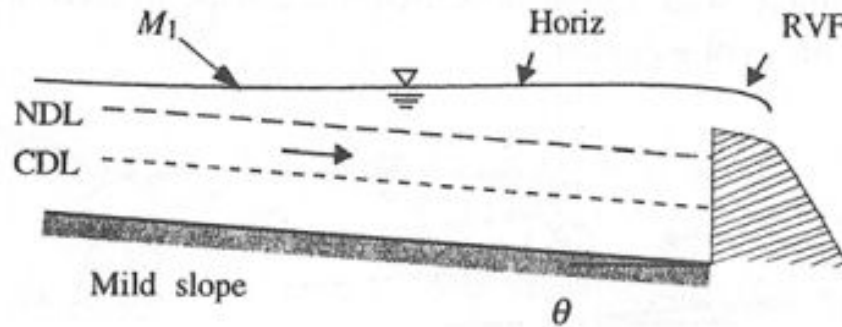


Figure 6.5. M_1 Profile

Gradually-Varied Flow

b) M_2 - Curve

Water surface will be in Region 2 for a mild slope channel and the flow is obviously subcritical. (Fig. 6.4).

$$y_0 > y > y_c$$

$$y < y_0 \rightarrow V > V_0 \rightarrow S_e > S_0 \rightarrow (S_0 - S_e) < 0$$

$$y > y_c \rightarrow F_r < 1 \rightarrow (1 - F_r^2) > 0$$

$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2} = \frac{-}{+} = - \quad (\text{Water depth decrease in the flow direction})$$

$$y > y_c \rightarrow F_r < 1$$

$$y = y_c \rightarrow F_r = 1$$

$$y < y_c \rightarrow F_r > 1$$

$$y > y_0 \rightarrow S_e < S_0$$

$$y = y_0 \rightarrow S_e = S_0$$

$$y < y_0 \rightarrow S_e > S_0$$

Gradually-Varied Flow

The M_2 profiles occur at a sudden drop of the channel, at constriction type of transitions and at the canal outlet into pools (Fig. 6.6).

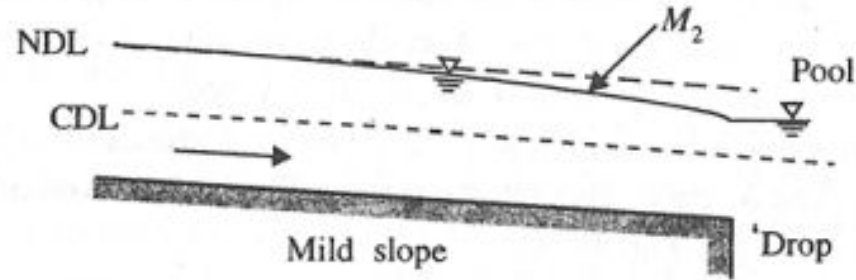


Figure 6.6

Gradually-Varied Flow

c) M_3 - Curve

Water surface will be in Region 3 for a mild slope channel and the flow is obviously subcritical. (Fig. 6.4).

$$y_0 > y_c > y$$

$$y < y_0 \rightarrow V > V_0 \rightarrow S_e > S_0 \rightarrow (S_0 - S_e) < 0$$

$$y < y_c \rightarrow \text{Supercritical flow} \rightarrow F_r > 1 \rightarrow (1 - F_r^2) < 0$$

$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2} = \frac{-}{-} = + \quad (\text{Water depth will increase in the flow direction})$$

$$y > y_c \rightarrow F_r < 1$$

$$y = y_c \rightarrow F_r = 1$$

$$y < y_c \rightarrow F_r > 1$$

$$y > y_0 \rightarrow S_e < S_0$$

$$y = y_0 \rightarrow S_e = S_0$$

$$y < y_0 \rightarrow S_e > S_0$$

Gradually-Varied Flow

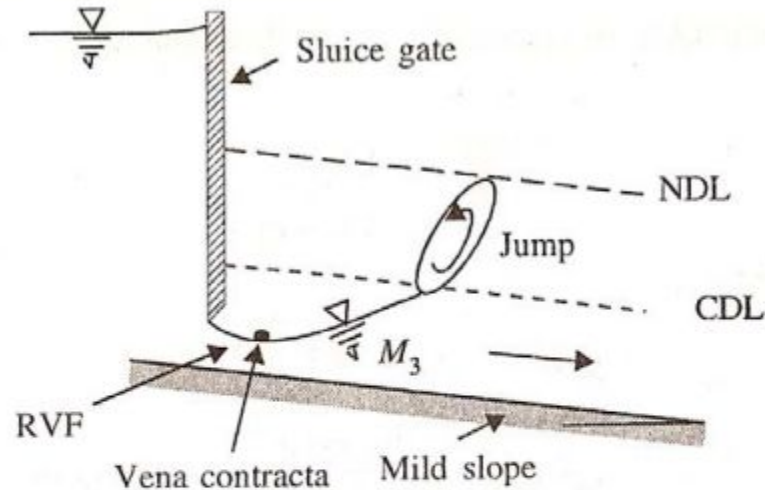


Figure 6.7. M₃ Profile

Where a supercritical stream enters a mild slope channel, M₃ type of profile occurs. The flow leading from a spillway or a sluice gate to a mild slope forms a typical example (Fig. 6.7). The beginning of the M₃ curve is usually followed by a small stretch of rapidly varied flow and the downstream is generally terminated by a hydraulic jump. Compared to M₁ and M₂ profiles, M₃ curves are of relatively short length.

Gradually-Varied Flow

Home Task A rectangular channel with a bottom width of 4.0 m and a bottom slope of 0.0008 has a discharge of 1.50 m³/sec. In a gradually varied flow in this channel, the depth at a certain location is found to be 0.30 m. assuming $n = 0.016$, determine the type of GVF profile.

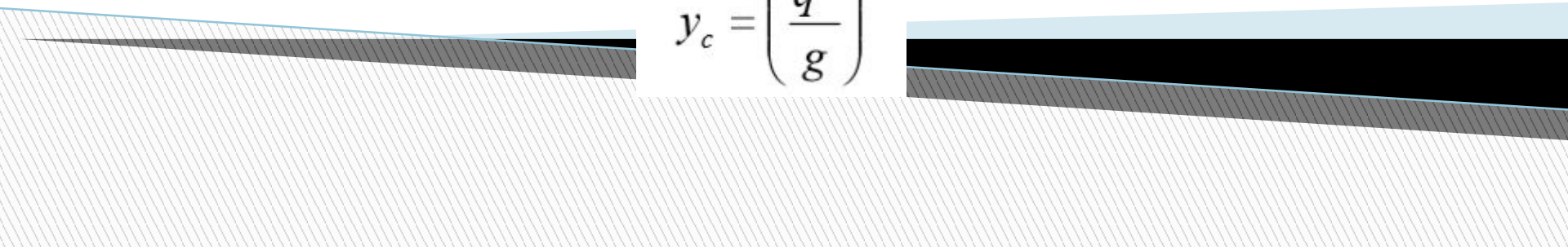
$$y > y_0 > y_c$$

$$y_0 > y > y_c$$

$$y_0 > y_c > y$$

$$Q = A \frac{1}{n} R^{2/3} S_0^{1/2}$$

$$y_c = \left(\frac{q^2}{g} \right)^{1/3}$$



Example 4.1

A rectangular channel with a bottom width of 4.0 m and a bottom slope of 0.0008 has a discharge of 1.50 m³/s. In a gradually varied flow in this channel, the depth at a certain location is found to be 0.30 m. Assuming $n = 0.016$, determine the type of GVF profile.

Solution (a) To find the normal depth y_0

$$\phi = \frac{Qn}{\sqrt{S_0} B^{5/3}} = \frac{1.50 \times 0.016}{\sqrt{0.0008} \times (4.0)^{5/3}} = 0.021046$$

Referring to Table 3A:1, the value of y_0/B for this value of ϕ , by interpolation, is

$$\frac{y_0}{B} = 0.1065$$

$$y_0 = 0.426 \text{ m}$$

(b) Critical depth y_c

$$q = Q/B = \frac{1.5}{4.0} = 0.375 \text{ m}^3/\text{s}/\text{m}$$

$$y_c = (q^2/g)^{1/3} = \left(\frac{(0.375)^2}{9.81} \right)^{1/3} = 0.243 \text{ m}$$

(c) Type of profile

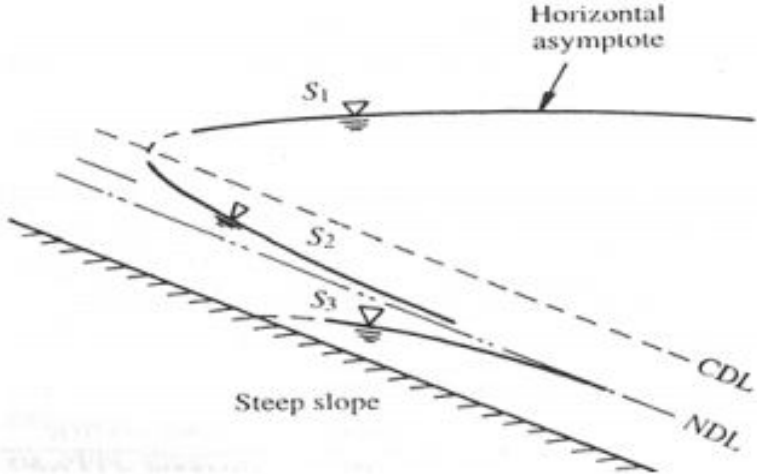
Since $y_0 > y_c$, the channel is a mild-slope channel. Also, given $y = 0.30 \text{ m}$ is such that

$$y_0 > y > y_c.$$

As such the profile is of the M_2 type (Table 4.2).

Gradually-Varied Flow

S - Curves



$$y > y_c > y_0$$
$$y_c > y > y_0$$
$$y_c > y_0 > y$$

Gradually-Varied Flow

a) S_1 - Curve

Water surface will be in Region 1 for a steep slope channel and the flow is obviously supercritical.

$$y > y_c > y_0$$

$$y > y_0 \rightarrow V < V_0 \rightarrow S_e < S_0 \rightarrow (S_0 - S_e) > 0$$

$$y > y_c \rightarrow F_r < 1 \rightarrow (1 - F_r^2) > 0$$

$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2} = \frac{+}{+} = +$$

(Water depth will increase in the flow direction)

$$y > y_c \rightarrow F_r < 1$$

$$y = y_c \rightarrow F_r = 1$$

$$y < y_c \rightarrow F_r > 1$$

$$y > y_0 \rightarrow S_e < S_0$$

$$y = y_0 \rightarrow S_e = S_0$$

$$y < y_0 \rightarrow S_e > S_0$$

Gradually-Varied Flow

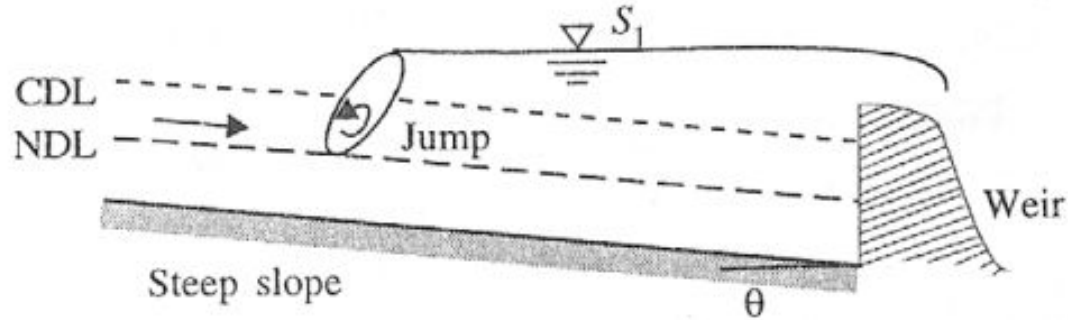


Figure 6.9. S_1 Profile

The S_1 profile is produced when the flow from a steep channel is terminated by a deep pool created by an obstruction, such as a weir or dam (Fig. 6.9). At the beginning of the curve, the flow changes from the normal depth (supercritical flow) to subcritical flow through a hydraulic jump. The profiles extend downstream with a positive water slope to reach a horizontal asymptote at the pool elevation.

Gradually-Varied Flow

b) S_2 - Curve

Water surface will be in Region 2 for a steep slope channel and the flow is supercritical.

$$y_0 < y < y_c$$

$$y > y_0 \rightarrow S_e < S_0 \rightarrow (S_0 - S_e) > 0$$

$$y < y_c \rightarrow \text{Supercritical flow} \rightarrow F_r > 1 \rightarrow (1 - F_r^2) < 0$$

$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2} = \frac{+}{-} = -$$

(Water depth will decrease in the flow direction)

$$y > y_c \rightarrow F_r < 1$$

$$y = y_c \rightarrow F_r = 1$$

$$y < y_c \rightarrow F_r > 1$$

$$y > y_0 \rightarrow S_e < S_0$$

$$y = y_0 \rightarrow S_e = S_0$$

$$y < y_0 \rightarrow S_e > S_0$$

Gradually-Varied Flow

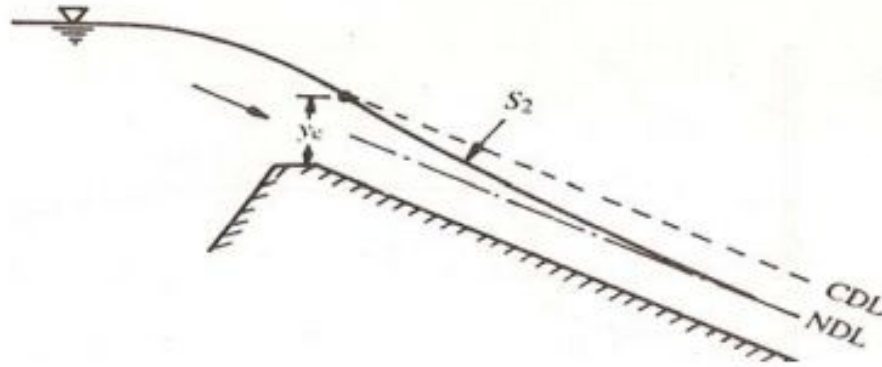


Figure 6.10. S_2 Profile

Profiles of the S_2 type occur at the entrance region of a steep channel leading from a reservoir and at a brake of grade from mild slopes to steep slope (Fig. 6.10). Generally S_2 profiles are short of length.

Gradually-Varied Flow

c) S_3 - Curve

Water surface will be in Region 3 for a steep slope channel and the flow is supercritical.

$$y_c > y_0 > y$$

$$y < y_0 \rightarrow S_e > S_0 \rightarrow (S_0 - S_e) < 0$$

$$y < y_c \rightarrow \text{Supercritical flow} \rightarrow F_r > 1 \rightarrow (1 - F_r^2) < 0$$

$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2} = \frac{-}{-} = +$$

(Water depth will increase in the flow direction)

$$y > y_c \rightarrow F_r < 1$$

$$y = y_c \rightarrow F_r = 1$$

$$y < y_c \rightarrow F_r > 1$$

$$y > y_0 \rightarrow S_e < S_0$$

$$y = y_0 \rightarrow S_e = S_0$$

$$y < y_0 \rightarrow S_e > S_0$$

Gradually-Varied Flow

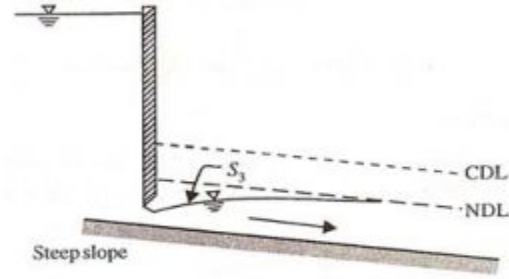


Figure 6.11. S_3 Profile

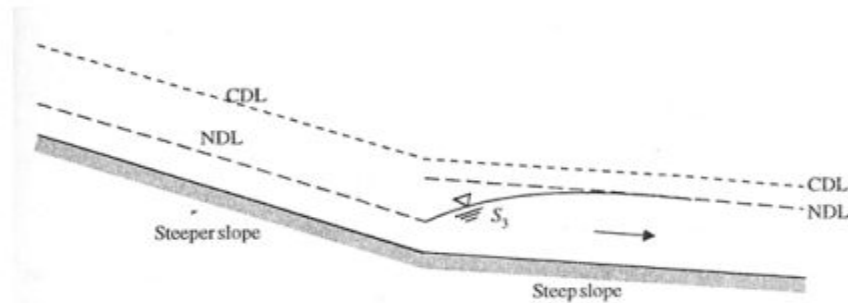
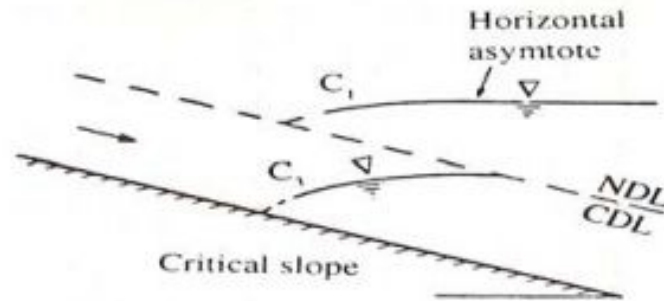


Figure 6.12. S_3 Profile

Free flow from a sluice gate with a steep slope on its downstream is of the S_3 type (Fig. 6.11). The S_3 curve also results when a flow exists from a steeper slope to a less steep slope (Fig. 6.12).

Gradually-Varied Flow

6.4.3. C – Curves



$$y > y_0 = y_c$$

$$y < y_0 = y_c$$

Figure 6.13

General shapes of C curves are given in Fig. (6.13). Asymptotic behaviors of each curve will be examined mathematically. Since the flow is at critical stage, $y_0 = y_c$, there is no Region 2.

Gradually-Varied Flow

a) C_1 - Curve

Water surface will be in Region 1 for a critical slope channel.

$$y_0 = y_c < y < \infty$$

$$y > y_c \rightarrow S_e < S_0 \rightarrow (S_0 - S_e) > 0$$

$$y > y_c \rightarrow \text{Subcritical flow} \rightarrow F_r < 1 \rightarrow (1 - F_r^2) > 0$$

$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2} = \frac{+}{+} = +$$

(Water depth will increase in the flow direction)

$$y > y_c \rightarrow F_r < 1$$

$$y = y_c \rightarrow F_r = 1$$

$$y < y_c \rightarrow F_r > 1$$

$$y > y_0 \rightarrow S_e < S_0$$

$$y = y_0 \rightarrow S_e = S_0$$

$$y < y_0 \rightarrow S_e > S_0$$

Gradually-Varied Flow

6.4.4. H – Curves

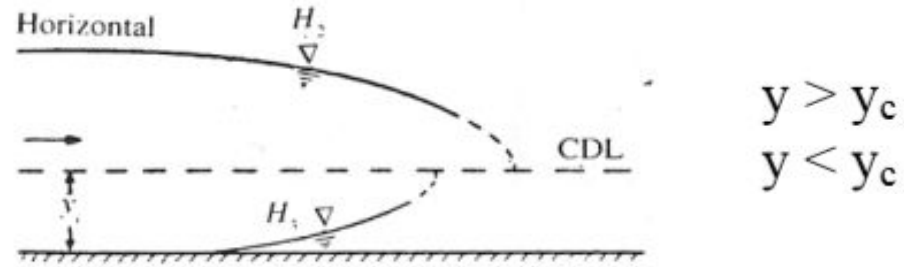


Figure 6.14

General shapes of H curves are given in Fig. (6.14). For horizontal slope channels, uniform flow depth y_0 does not exist. Critical water depth can be computed for a given discharge Q and therefore critical water depth line can be drawn. Since there is no uniform water depth y_0 , Region 1 does not exist.

Gradually-Varied Flow

a) H_2 - Curve

Water surface will be in Region 2 for a horizontal slope channel.

$$\infty > y > y_c$$

$$y > y_c \rightarrow S_e < S_0 = 0 \rightarrow (S_0 - S_e) > 0$$

$$y > y_c \rightarrow \text{subcritical flow} \rightarrow F_r < 1 \rightarrow (1 - F_r^2) > 0$$

$$\frac{dy}{dx} = \frac{+}{+} = + \quad (\text{Water depth will increase in the flow direction})$$

$$y > y_c \rightarrow F_r < 1$$

$$y = y_c \rightarrow F_r = 1$$

$$y < y_c \rightarrow F_r > 1$$

$$y > y_0 \rightarrow S_e < S_0$$

$$y = y_0 \rightarrow S_e = S_0$$

$$y < y_0 \rightarrow S_e > S_0$$

Gradually-Varied Flow

b) H_3 - Curve

$$y < y_c$$

$$y < y_c \rightarrow S_e > S_0 = 0 \rightarrow (S_0 - S_e) = < 0$$

$$y \rightarrow y_c, \text{ supercritical flow, } F_r > 1 \rightarrow (1 - F_r^2) < 0$$

$$\frac{dy}{dx} = \frac{S_0 - S_e}{1 - F_r^2} = \frac{-}{-} = +$$

(Water depth will increase in the flow direction)

$$y > y_c \rightarrow F_r < 1$$

$$y = y_c \rightarrow F_r = 1$$

$$y < y_c \rightarrow F_r > 1$$

$$y > y_0 \rightarrow S_e < S_0$$

$$y = y_0 \rightarrow S_e = S_0$$

$$y < y_0 \rightarrow S_e > S_0$$

Gradually-Varied Flow

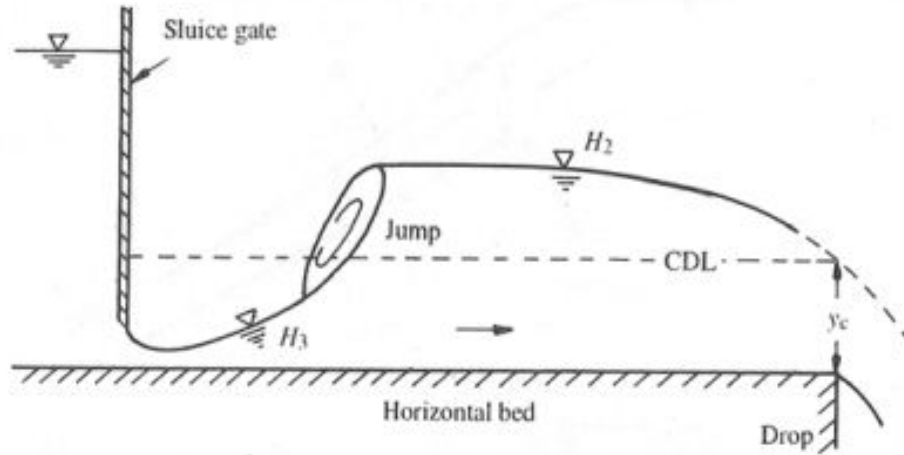


Figure 6.15

A horizontal channel can be considered as the lower limit reached by a mild slope as its bed slope becomes flatter. The H_2 and H_3 profiles are similar to M_2 and M_3 profiles respectively (Fig. 6.15). However, the H_2 curve has a horizontal asymptote.

Gradually-Varied Flow

6.4.5. A- Curves

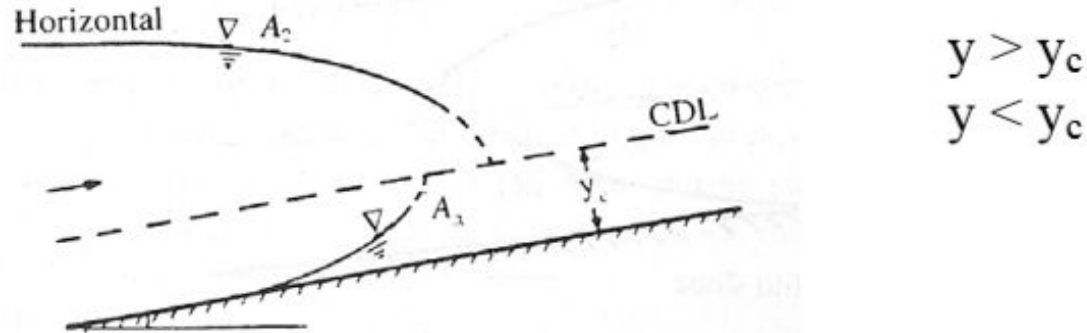


Figure 6.16

General shapes of A curves are given in Fig. (6.16). For adverse slope channels, uniform flow depth y_0 does not exist. Critical water depth can be computed for a given discharge Q and therefore critical water depth line can be drawn. Since there is no uniform water depth y_0 , Region 1 does not exist as well as in A curves. A_2 and A_3 curves are similar to H_2 and H_3 curves respectively.

Gradually-Varied Flow

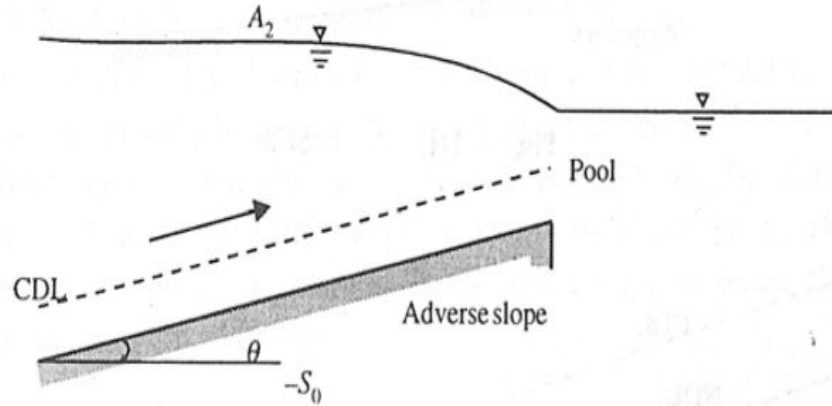
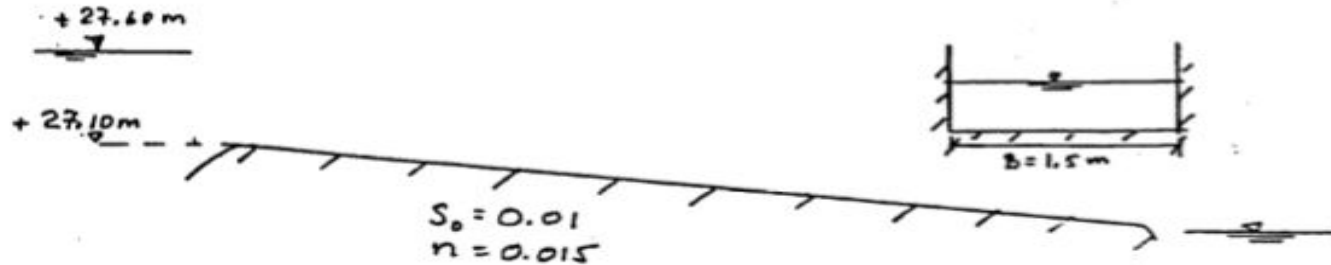


Figure 6.17

Adverse slopes are rather rare (Fig. 6.17). These profiles are of very short length.

Gradually-Varied Flow



A long channel with the bottom slope $S_0 = 0.01$ and the Manning $n = 0.015$ has got a rectangular cross section with the bottom width $B = 1.5\text{ m}$. The channel starts at an upstream reservoir with the water level at $+27.60\text{ m}$ and the inlet threshold is at $+27.10\text{ m}$. The water level of the downstream reservoir is low.

- What is the flow rate Q in the channel?
- Which water surface profile (letter + number) will be obtained downstream of the inlet section?
- What is the critical bottom slope $S_0 = S_c$? Use the flow rate Q according to point a.

See You Next Week!!!

Next Lecture.....

Computation of flow profiles

