Water Surface Profiles

Computation Procedure

1. **Data Collection:** Obtain all channel and flow information including channel shape (or x-sections at pertinent locations), channel slope, and Manning roughness factor.
2. **Control Section:** Determine the location of the control section (boundary condition) including depth and flow.
3. **Channel Depths:** Compute normal and critical depths .
4. **Channel Classification:** Determine if the channel is mild (M), steep (S), critical (C), horizontal (H), or adverse (A).
5. **Water Surface Profile Classification:** Classify the flow as Type 1, 2, or 3 based on flow depth (y), y_n and y_c.

Standard Step Method Review

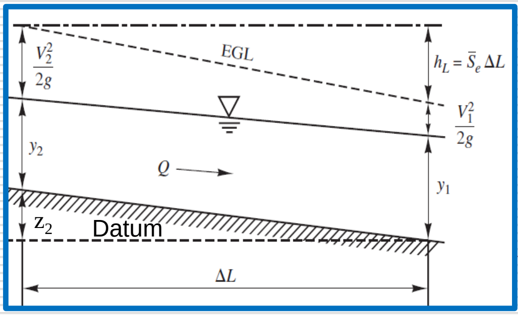
(Gradually Varied Flow)

Computational Algorithms: Energy Balance & Manning eq'n:

$$z_2 + y_2 + (V_2)^2/2g = z_1 + y_1 + (V_1)^2/2g + \Delta L(S_e)_{avg}$$

For SI: $S_e = n^2V^2/(R_h)^{4/3}$ For BG: $S_e = n^2V^2/[2.22(R_h)^{4/3}]$

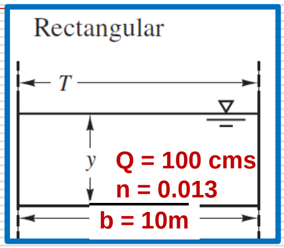
$(S_e)_{avg}$ is the average EGL at upstream & downstream sections.



Process: Use successive computations starting at the control section. Find flow depths by balancing energy between adjacent x-sections going upstream for subcritical flow.

Water Surface Profile Computations

(Example Problem – Standard Step Method)



Given: Concrete channel with $S_o = 0.001$, that ends in a waterfall (drop-off). ➔

Find: Depths of flow at 5m, 25m, and 100m upstream of the waterfall.

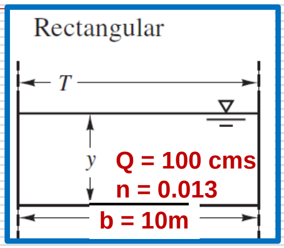
Solution Steps: (from previous slides)

1. **Data Collection:** Available from problem statement.
2. **Control Section:** Critical depth (y_c) occurs at drop-off.
3. **Channel Depths:** Determine y_n and y_c for the channel.

$q = Q/b = 10$ cms/m; y_c =

Water Surface Profile Computations

(Example Problem – Standard Step Method)



3b. Channel Depths: Determine y_n.

From Table 6.1: $A = 10y$ & $P = 10 + 2y$

$Q = (1/n)AR_h^{2/3}S_o^{1/2} = (1/n)(A^{5/3}/P^{2/3})S_o^{1/2}$

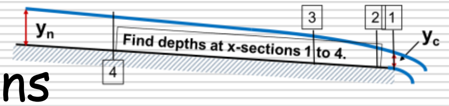
Thus, $Qn/S_o^{1/2} = (100*0.013)/(0.001)^{1/2}$ =

$41.1 = (10y_n)^{5/3}/[10+2y_n]^{2/3}$; $y_n = 2.79$m

4. Channel Classification: Since $y_n > y_c$ ➔ Channel is

5. Water Surface Profile Classification: Depth rises from y_c at the drop-off to y_n upstream ➔ **M2**. Sketch it.

Water Surface Profile Computations



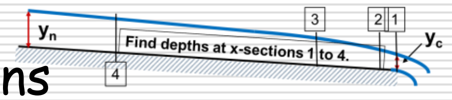
In subcritical flow, calculations progress upstream starting at the control section ($y_1 = y_c = 2.17$m; boundary condition). Try to balance energy between sections 1 and 2 with a trial depth ($y_2 = 2.35$m). Assume $z_1 = 0.00$m. A table is helpful.

Sec.	U/D	y	z	A	V	$V^2/2g$	P	R_h	S_e	$S_{e(avg)}$	h_L	Total E
#		(m)	(m)	(m^2)	(m/sec)	(m)	(m)	(m)			(m)	(m)
1	D	2.17	0.000	21.70	4.608	1.0824	14.340	1.513	0.002066	0.001851	0.0093	3.262
2	U	2.35	0.005	23.50	4.255	0.9229	14.700	1.599	0.001637	$\Delta L =$	5	3.278
Note:	The trial depth of 2.35 m is incorrect since energies don't balance Try a smaller depth at Section 2.											

$$z_u + y_u + (V_u)^2/2g = z_D + y_D + (V_D)^2/2g + \Delta L(S_e)_{avg}$$

For SI: $S_e = n^2V^2/(R_h)^{4/3}$ For BG: $S_e = n^2V^2/[2.22(R_h)^{4/3}]$

Water Surface Profile Computations



Try to balance energy between sections 1 and 2 again with a new trial depth ($y_2 = 2.25$m). Fill in the blanks in the table.

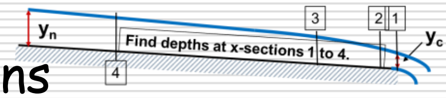
Sec.	U/D	y	z	A	V	$V^2/2g$	P	R_h	S_e	$S_{e(avg)}$	h_L	Total E
#		(m)	(m)	(m^2)	(m/sec)	(m)	(m)	(m)			(m)	(m)
1	D	2.17	0.000	21.70	4.608	1.0824	14.340	1.513	0.002066	0.001962	0.0098	3.262
2	U	2.25	0.005			1.0068				$\Delta L =$	5	
Note:	The trial depth of 2.25 m is correct. Now balance energy between sections #2 and #3.											

$$z_u + y_u + (V_u)^2/2g = z_D + y_D + (V_D)^2/2g + \Delta L(S_e)_{avg}$$

For SI: $S_e = n^2V^2/(R_h)^{4/3}$ For BG: $S_e = n^2V^2/[2.22(R_h)^{4/3}]$

Note: Errors propagate, so use more significant figures than normal.

Water Surface Profile Computations



Now balance energy between sections 2 (y_2 = 2.25m) and 3 (trial depth ➔ y_3 = 2.35m). Fill in the blanks in the table.

Sec.	U/D	y	z	A	V	$V^2/2g$	P	R_h	S_e	$S_{e(avg)}$	h_L	Total E
#		(m)	(m)	(m^2)	(m/sec)	(m)	(m)	(m)			(m)	(m)
2	D	2.25	0.005	22.50	4.444	1.0068	14.500	1.552	0.001858	0.001748	0.0350	
3	U	2.35		23.50	4.255	0.9229				ΔL =		
	Note: The trial depth of 2.35 m is correct. Now balance energy between sections #3 and #4.											

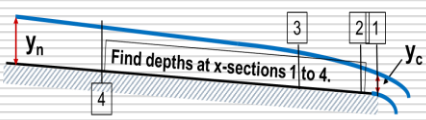
$$z_u + y_u + (V_u)^2/2g = z_D + y_D + (V_D)^2/2g + \Delta L(S_e)_{avg}$$

For SI: $S_e = n^2V^2/(R_h)^{4/3}$ For BG: $S_e = n^2V^2/[2.22(R_h)^{4/3}]$

Note: Energy balance should be very close before proceeding.

Water Surface Profile Computations

(Standard Step Method – Final Comments)



Section #	Depth (y)	Distance*
1	2.17 m	0
2	2.25 m	5
3	2.35 m	25
4	2.49 m	100

*Distance upstream from waterfall.

Notes: X-section spacing should be quite close when depths change rapidly.

Normal depth (2.79m) has not been reached in the channel. It will be approached asymptotically as additional sections are added further upstream. An iterative procedure is not necessary in the direct step method (see textbook). However, it will only work with prismatic channels. Also, it is easy to program a spreadsheet to do the calculations.

Hydraulic Design of Open Channels
(Generally Designed for Uniform Flow)

Design Requirements: Channel size, shape, slope, alignment, and liner.

Liner Types:

Primary Design Equation:

Design Constraints: Topography, right-of-way, adjacent structures, proposed liner, depth of groundwater table, cost, $N_F \ll 1.0$ (subcritical), and freeboard.

Slope Stability: Based on channel liner material (Table 6.6)

Hydraulic Design of Open Channels
(Unlined and Rigid Boundary Channels)

Unlined Channels: excavated in existing soil on site

Design channel so that the average V doesn't exceed V_{max} for channel material

Design channel so that the shear stress (τ) on the channel liner doesn't exceed the $\tau_{allowable}$

Rigid (non-erodible) Boundary Channels: Use the "best hydraulic" section concept (Section 6.3). The conveyance capacity of a channel section for a given flow area is maximized when the wetted perimeter is minimized.

Homework: