EWCE 461 — SA

Rough / L02 30/06

Rivers & Alluvial Rivers

River → channelized flow of water w/ definable boundaries.
Overland flow → non-channelized; low depth (cm) but very wide.

surface runoff
↳ overland flow → channelized → narrow (rills) → Gullies → River

Classification of freshwater flow

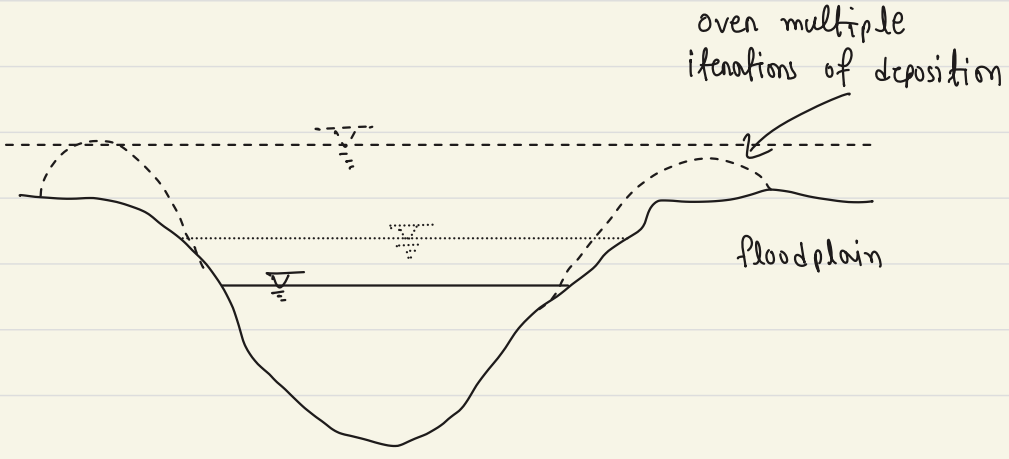
Rivulet	Creek	Stream	River
cm	meters	tens of m	>50m
<0.5	1–5 m	10 - 30m	
[1st order]	[2nd order]	[3rd order]	[4th & up]

Long profile → three main zones

1. Erosional zone → erodes, steep slope, boulders, cobbles, gravels
2. Transport " → equilibrium, gravel, sands, mild slope
3. Depositional " → net sedimentation, aggregades, sand–silt, clay flat

Definitions:

Levee →

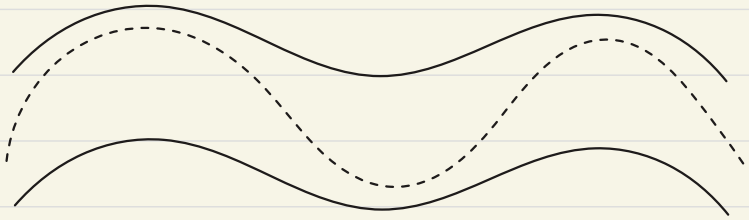


Floodplain → Area adjacent to river that floods once in two years or twice in three years.

Delta v. Estuary

Feature	Delta	Estuary
Dominant force	Upland flow	Tidal flow
Primary process	Sedimentation	Erosion
Shape	Roughly triangular	Funnel
Land formation	Forms new land	Does not
Water type	Freshwater	Seawater
Fertility	High	Low

Thalweg : Imaginary line connecting deepest point along long profile



River classification:

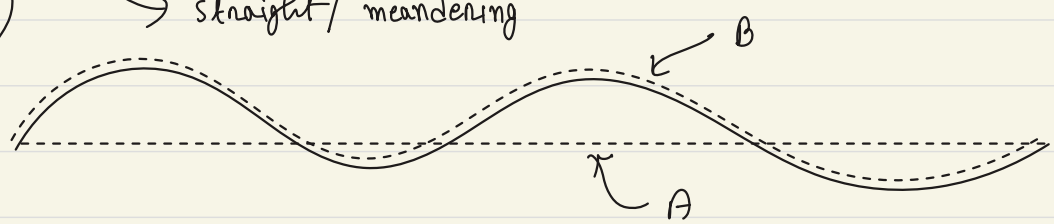
1. By nature of their substrate: material above which the river flows → bedrock and alluvial.

2. Percentage of time they flow:
   Perennial, ephemeral, intermittent

3. Relⁿ to GWT
   Influent, effluent

4. Sedimentation load:
   Bed load → coarse sand, gravel (>11%)
   suspended load → clay, silt, fine sand (<3%)
   mixed load
   braided ; depth-width = >40 ; sinuosity < 1.3 ; steep
   meandering ; " <10 ; " > 2.0 ; gentle slope

5. morphology → braided
   sinuosity, multichannelledness
   → straight/ meandering



$\frac{B}{A} \times 100$ %

Sinuosity > 1.5 for meandering

Low sinuosity + multichannel → braided

High " + single channel → meandering

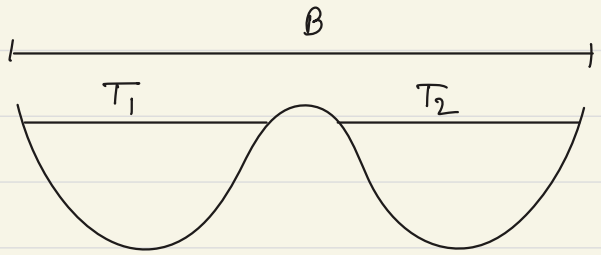
Planform index (PFI)

$$PFI = \frac{\Sigma T / B}{N} \times 100$$

[< 3 → highly braided

< 20 → moderately "

> 20 → low "



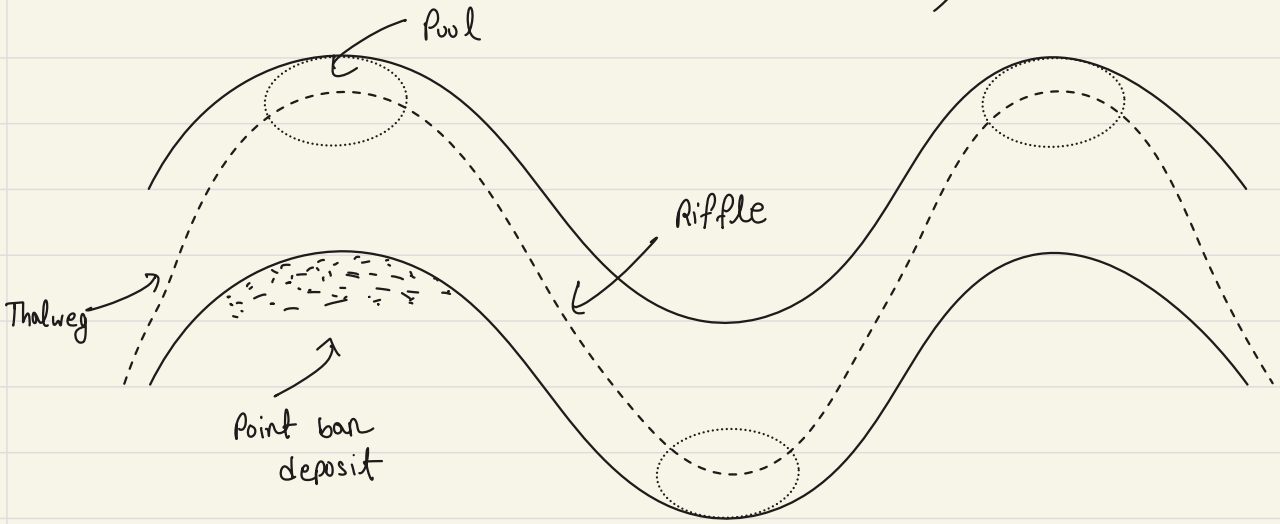
N : 2

Rough / CT-2 11/07

Channel patterns (How the river looks in its plan view)

Straight river — none

Meandering — forms as stream erodes the banks
lie on fine-grained soil, has gentle slope
↖ hard to erode; cohesive

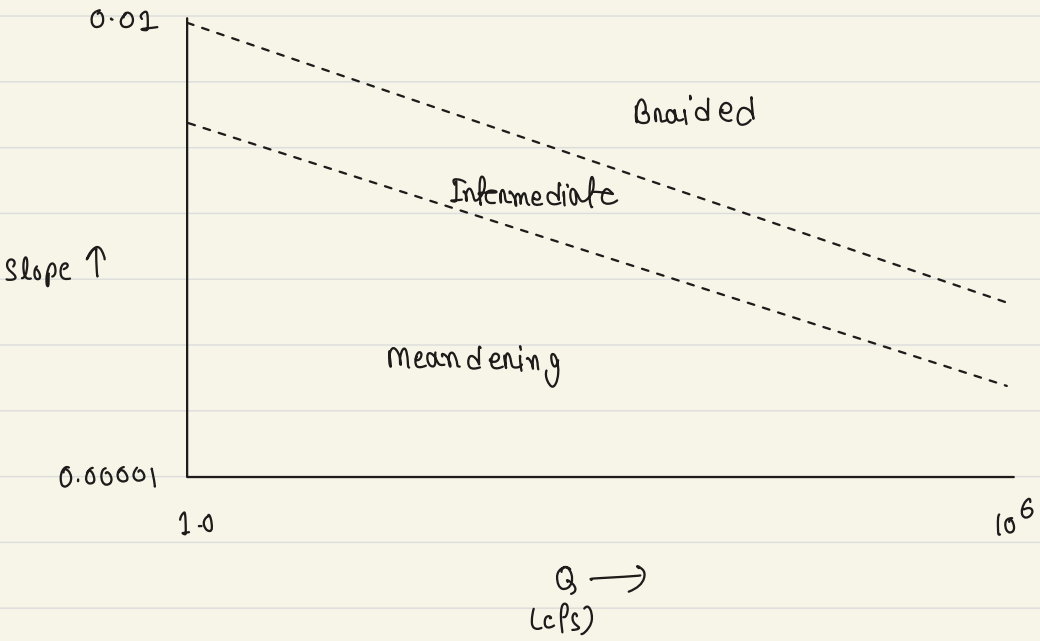


Braided — unable to move all load, hence deposits
easily erodable banks
High sediment load

Pattern variability :

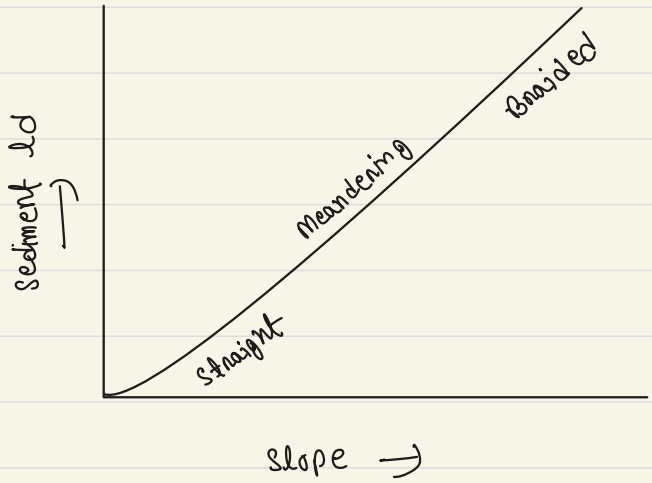
Variables affecting pattern variability : slope,
sediment ld,
sinuosity
width-depth ratio

Effect of slope : At a given discharge, as slope is increased,
straight → sinuous → braided



Effect of slope & sediment load:

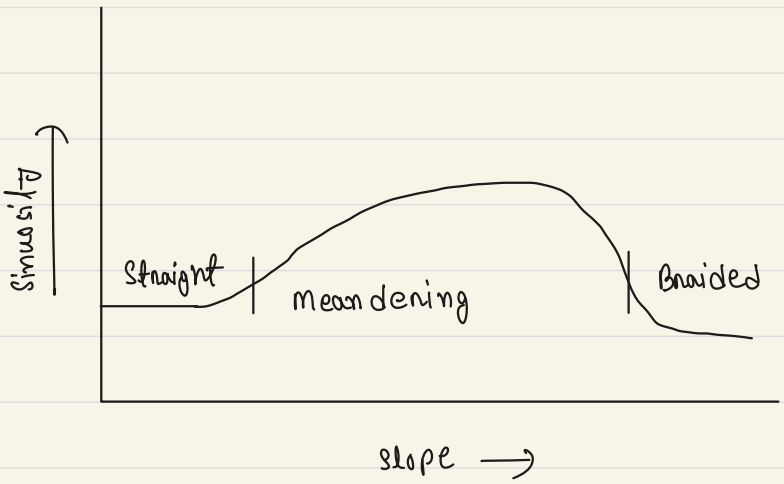
Slope ↑ → sediment load ↑ → braided



Effect of sinuosity:

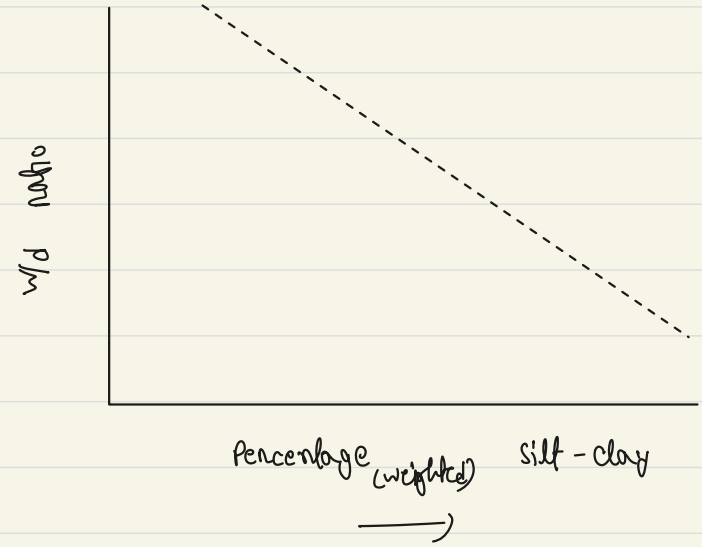
Slope ↑ → sinuosity ↑

Slope ↑↑ → Braided

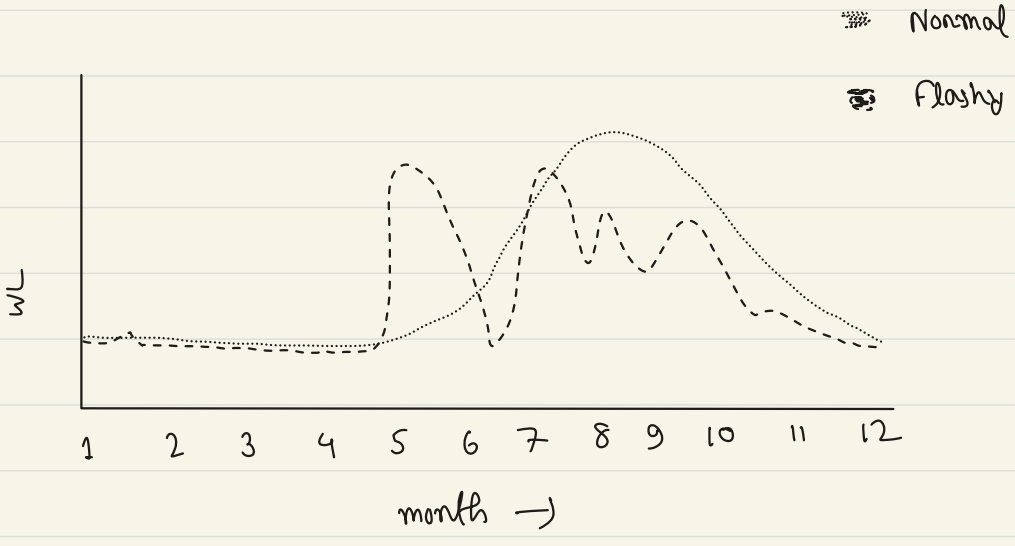


Width-depth ratio :

Cohesive soil → hard to erode (both sideways & bed)
→ becomes meandering and deepens
→ gets low w/d ratio



Based on flooding : Normal river
Flashy river



Hydraulic geometry: Changes in w, d, u w/ respect to discharge.

$w = aQ^b$; $d = cQ^f$; $u = kQ^m$

Again, $Q = w \cdot d \cdot u$

$\therefore Q = a \cdot c \cdot u \times Q^{(b+f+m)}$

or, $a \cdot c \cdot u = 1$

$b + f + m = 1$

Comes in two formats: At-a-station

D/s hydraulic geometry

Example: width & discharge given

Discharge Q (m^3/sec)	0.2	5.9	23	39.6	74.4
Width (m)	8	12	16	18	20

$w = aQ^b$

$\Rightarrow \underbrace{\log w}_{Y} = \underbrace{\log a}_{c} + \underbrace{b}_{m} \underbrace{\log Q}_{x}$

From graph, $w = 10.07 \times Q^{0.16}$

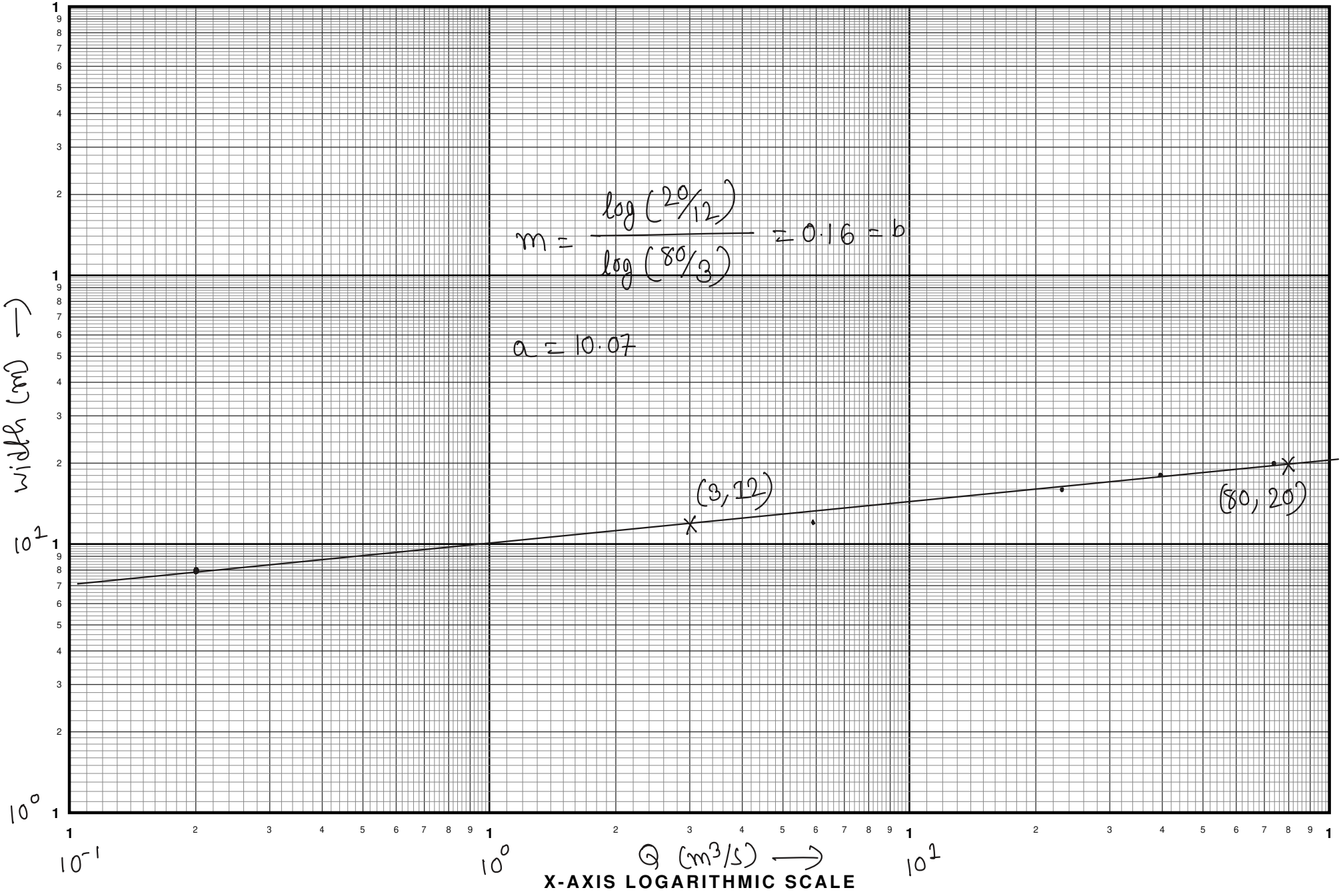
Again, $d = 0.4Q^{0.45}$

$\therefore u = \left(\frac{1}{10.07 \times 0.4}\right) \times Q^{1-(0.16+0.45)}$

$= 0.25 \times Q^{0.39}$

LOGARITHMIC GRID SHEET

3 × 3 Cycles • Landscape A4 Standard **DATE:** _____



Y-AXIS LOGARITHMIC SCALE

X-AXIS LOGARITHMIC SCALE

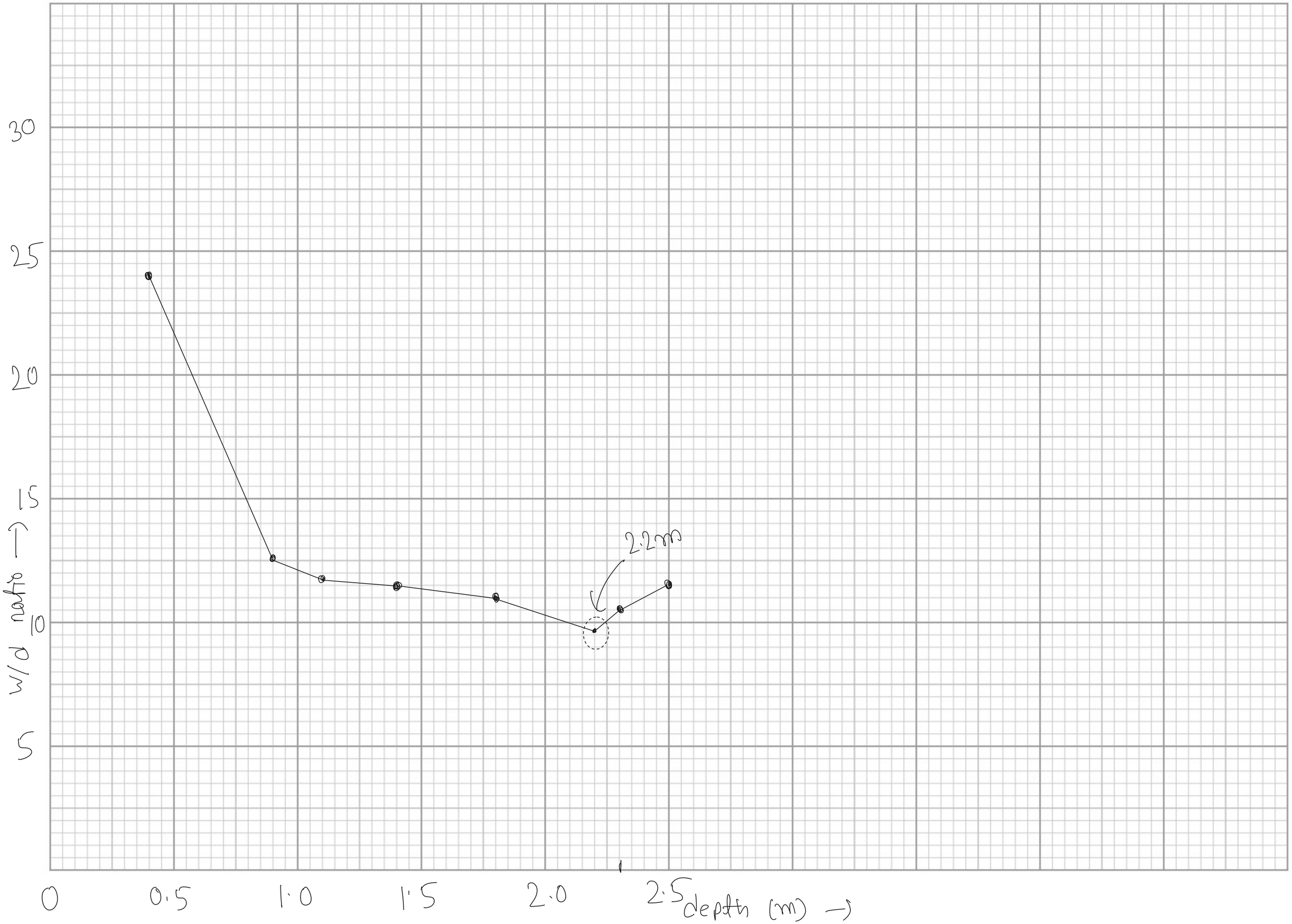
Bankfull discharge :

The flow of water of a stream just before it spills over into its adjacent floodplain.

Determine by, (i) depth against w/d ratio
(ii) cross-sectional area vs top width

Example :

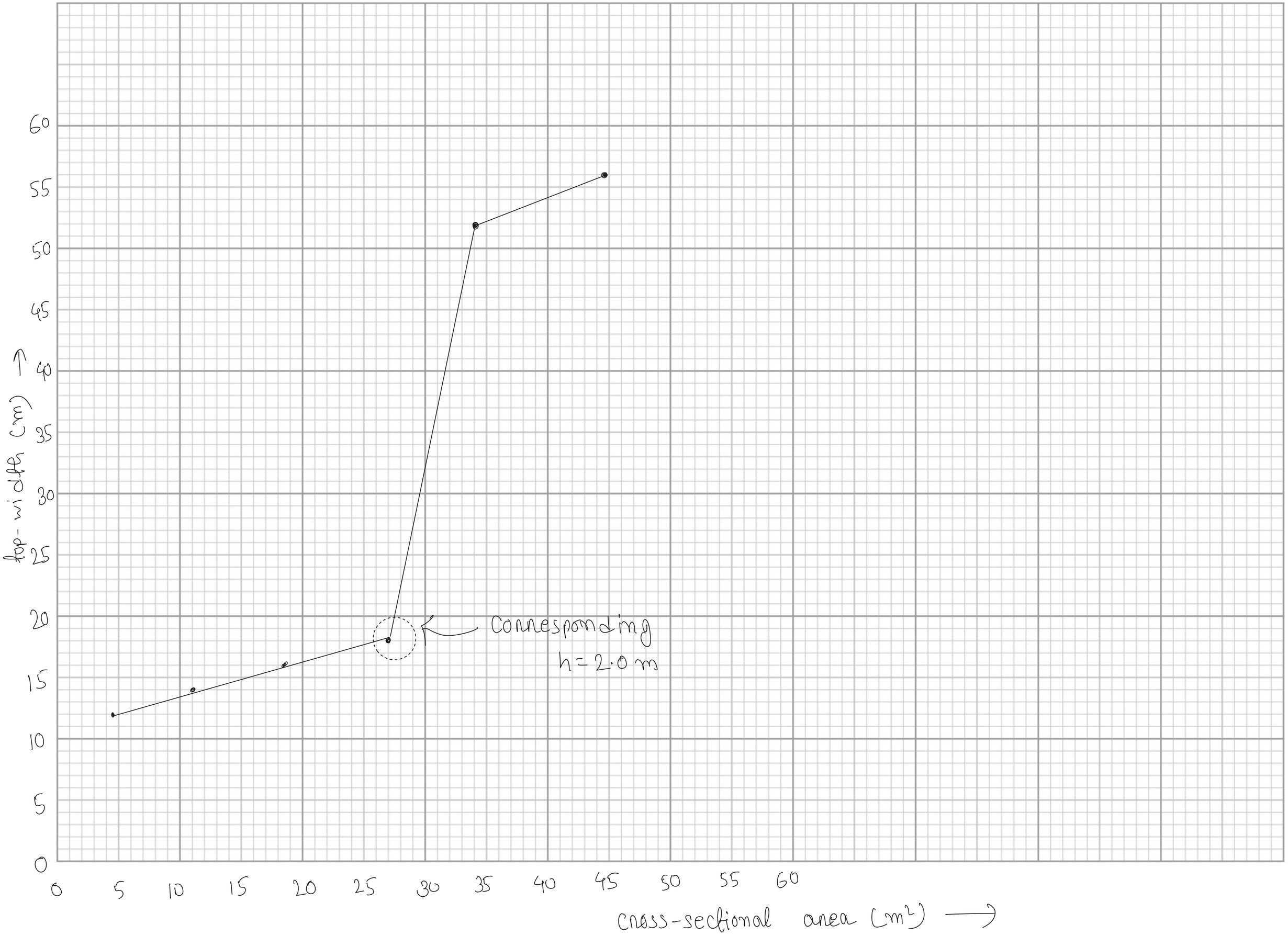
Depth (m)	0.4	0.9	1.1	1.4	1.8	2.2	2.3	2.5	2.8
Width (m)	9.6	11.3	13	16.1	19.8	20.9	24.2	28.8	35
W/D	24	12.6	11.8	11.5	11	9.6	10.5	11.5	


30
25
20
15
10
5
w/d ratio →
2.2m
0
0.5
1.0
1.5
2.0
2.5
depth (m) →

Example!

Given Data Table

Stage, h (m)	Top Width, W (m)	Cross-Sectional Area, A (m^2)
0.5	12.0	4.5
1.0	14.0	11.0
1.5	16.0	18.5
2.0	18.0	27.0
2.2	52.0	34.0
2.4	56.0	44.8


top-width (m) ↑
0
5
10
15
20
25
30
35
40
45
50
55
60
Corresponding
h = 2.0 m
cross-sectional area (m²) →

Dominant discharge:

Discharge that is equaled on exceeded 50% of the time

River slope:

Longitudinal slope of a river; continuous decrease.

$$S = S_0 e^{-\alpha x}$$

Reasonings for such profile:

1. Sediment load decrease (size reduction by grinding)
2. Deposition of sediments
3. Q increases by inflow from tributaries but not sediment

Sediment size:

$$w = w_0 e^{-\beta x}$$

$$d = d_0 e^{-cx}$$

Derived Hydraulic Relations:

For a typical river:

$w = aQ^{0.5}$; $d = cQ^{0.4}$; $v = kQ^{0.1}$; $s = tQ^{-1.0}$

in d/s, $Q\uparrow$; therefore, $v\uparrow$ however observation may deny

check w/ direct mats

Manning's roughness factor,

$$v = \frac{R^{2/3} S^{1/2}}{n} \Rightarrow n = \frac{d^{2/3} S^{1/2}}{v}$$

$$= \frac{ct\, Q^{(0.4 \times 2/3 - 0.5 \times 1 - 0.1)}}{k}$$

$$\Rightarrow n = \frac{c_3}{Q^{1/3}}$$

[At d/s, sediment size ↓ ↓ $n\downarrow \rightarrow Q\uparrow$]

Darcy – weisbach,

$$\frac{f_L}{L} = f \frac{1}{D} \frac{v^2}{2g}$$

$$\Rightarrow S = f \frac{1}{D} \frac{v^2}{2g}$$

$$\Rightarrow tQ^{-1} = f \frac{1}{cQ^{0.4}} \frac{k^2 Q^{0.2}}{2g}$$

$$\Rightarrow f = c_3 Q^{(-1 - 0.2 + 0.4)}$$

$$= c_3 Q^{-0.8}$$

Manning – Strickler, $n = 0.0478\, D_{50}^{1/6} = \frac{R^{2/3} S^{1/2}}{v}$

$$\rightarrow D_{50} = cQ^{-2}$$

Chezy's coeff, $v = C(RS)^{1/2}$; $v = \frac{1}{n} R^{1/6} (RS)^{1/2}$; $C = \frac{1}{n} R^{1/6} = c_1 Q^{0.3} \times c_2 Q^{0.4 \times 1/6}$

Change in velocity: $d^{2/3}$; $d = aQ^{0.4}$

$v = \frac{R^{2/3} S^{1/2}}{n}$; for any reasonable value, n & $S^{1/2}$ cancels each other

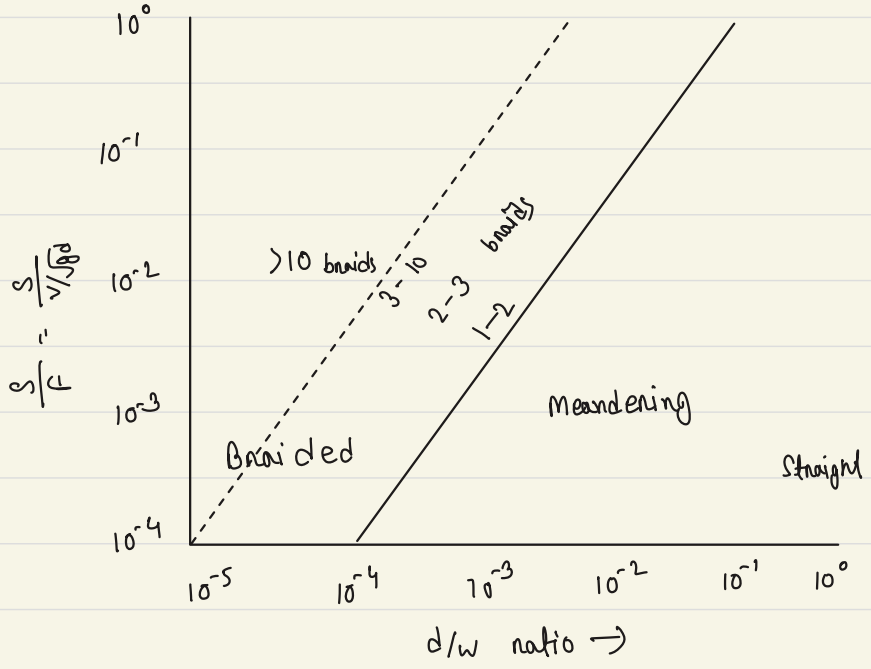
So, as river goes d/s, its velocity increases but not by much

As river goes d/s, $w \uparrow$
$d \uparrow$
$v \uparrow$
$S \downarrow \rightarrow$ sediment size $\downarrow \rightarrow n \downarrow$

Effect of S, w/d ratio, and sediment type

$w/d \uparrow \rightarrow$ braided
$\downarrow \rightarrow$ meandering

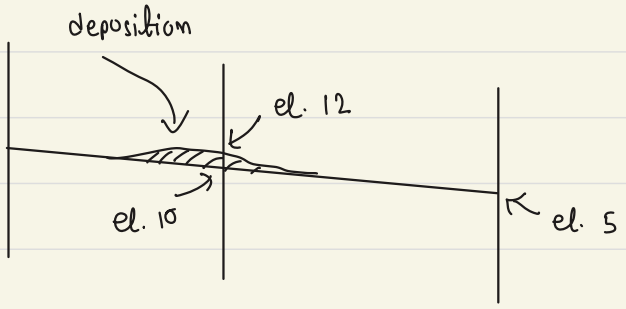
$d/w \uparrow \rightarrow$ meandering
$\downarrow \rightarrow$ braided



Process of meandering — Hypotheses :

1. Earth's rotation theory

2. Disturbance theory :



deposition increased slope → vel ↑ → adjust by eroding banks if not resisted

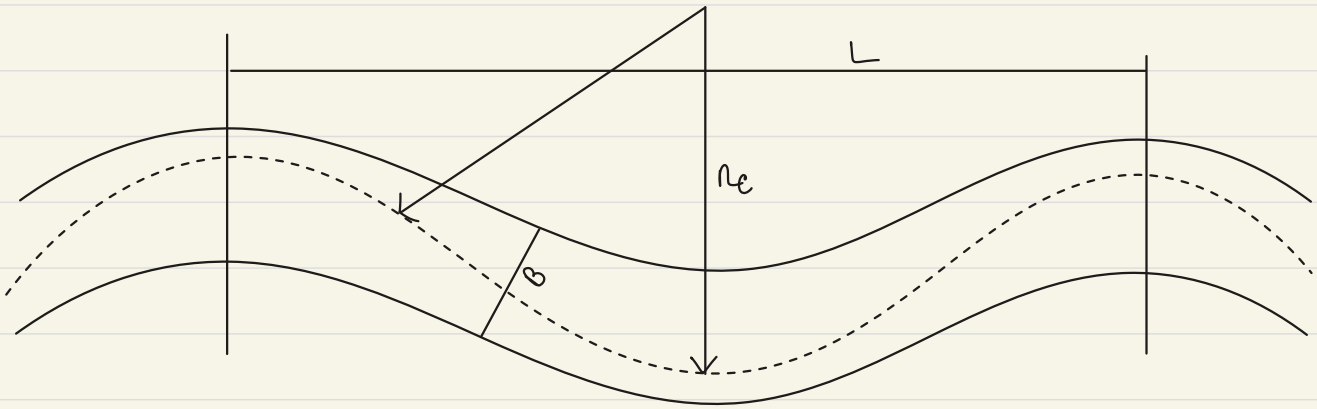
3. Excess energy theory :

Increase length by meandering ; decreases slope

4. Secondary flow theory

5. General wave motion arguments

Dimensional relationship in meandering channel



$$\frac{L}{B} \approx 7\text{-}10; \qquad \frac{r_c}{B} \approx 2\text{-}3$$

Meander length (λ) is a direct function of its bankfull width & radius of curvature but not its depth.

$$\lambda = C_1 r_c$$

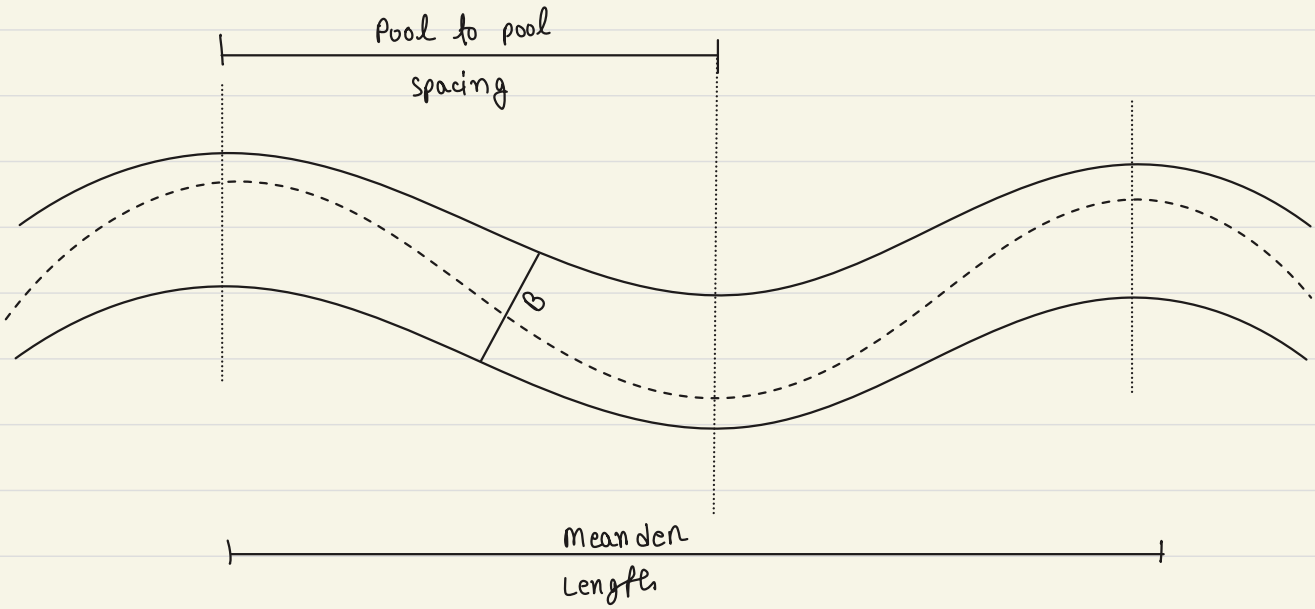
$$\lambda = C_2 W^n$$

$$r_c = C_3 W^m$$

$$m_L = a B^m$$

$$m_L = b R_m^n$$

Problem : P18



Width (m)	10	20	25	30	40
Spacing (m)	50	100	120	250	300

$$M_L = c\,W^n$$

$$\Rightarrow \frac{M_L}{2} = c_2 W^n$$

$$\Rightarrow SP = c_1 W^n$$

$$\therefore \log SP = \log c_1 + n \log W$$

($\log SP = Y$, $\log c_1 = C$, $n = m$, $\log W = X$)

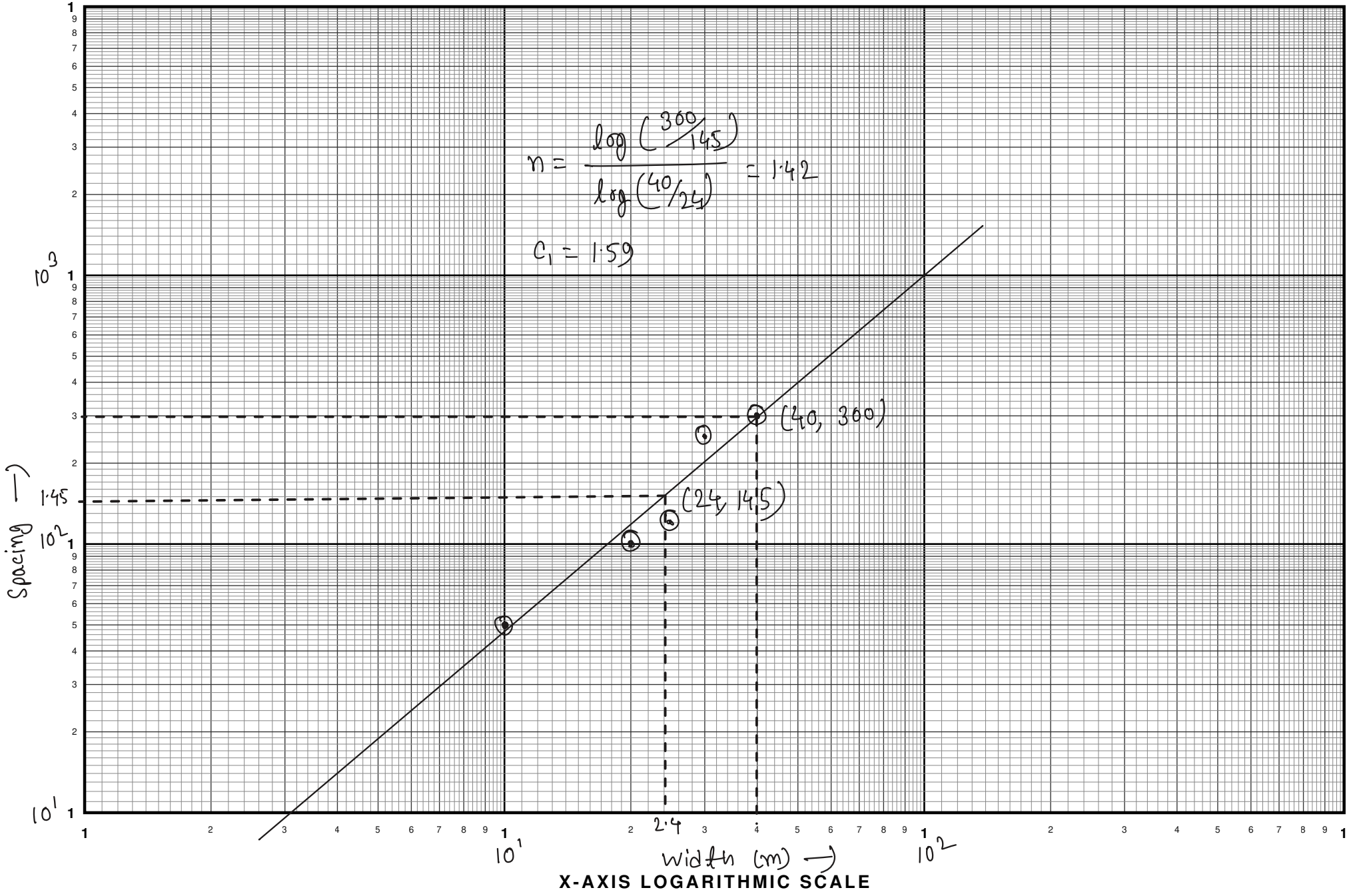
From graph, $SP = 1.59 \times W^{1.42}$

$\therefore M_L = 3.18 \times W^{1.42}$

Try to keep power close to one

LOGARITHMIC GRID SHEET

3 × 3 Cycles • Landscape A4 Standard **DATE:** _____



2.08

1.34

Rough / L04

22/07

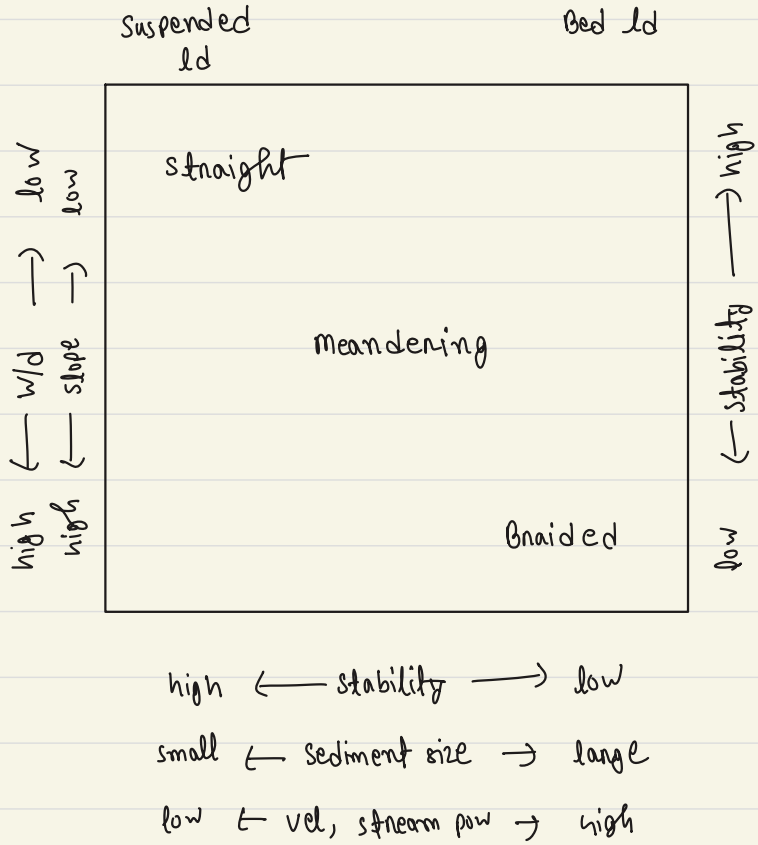
Causes of braiding:

Two primary causes → steep slope → vel ↑ → bank erosion → wide, shallow
high sediment load → deposit → multichannels

Another explanation → when the channel section is too wide, it can't act as a single unit.

Channel stability:

Channel dimension ← discharge
Shape, pattern ← + type & amount of sediment ld



high ← stability → low
small ← sediment size → large
low ← vel, stream pow → high

Analysis of Stability:

Based on the type of sediment load
Large / small ← discharge
Pattern, shape ← proportion of total sediment ld

Planform stability (PS):

$$PS1 = \frac{\text{Stream eroding power}}{\text{Boundary mat. strength}}$$

$$PS2 = \frac{\text{Bed load supply}}{\text{Bed load transport cap.}}$$

when PS1 is low, either mat strength ↑ or stream's eroding power ↓ → meandering
PS1 is high → braided

At PS2 ↓ → river able to carry sediment → meandering
↑ → deposits → mid-channel bars → braided

Modes of Sediment Transport:

Sediment ld → particles transported through flow.
Can be subdivided based on:

1. Physical nature → particulate, dissolved ld
2. Presence on absence in riverbed
   a. Wash ld → grain sizes are not present in the riverbed by an appreciable percentages
   b. Bed material ld → grain sizes are found on riverbed by non-negligible amount.
3. How they travel → suspended ld, bed ld

Bed load is always bed-material ld, but suspended ld can be both bed material ld and wash ld:

Bed material ld, are by definition, moves in contact with river bed (through rolling, sliding, salting). Hence, they are naturally represented in the river bed

Bed material ld, when turbulence increases, starts floating above the riverbed water column and becomes suspended load.
wash ld is always in suspended state. They never interact or rest on the bed.

Classification of sediment load:

	Predominate mode of transport	whether particle size present in channel bed
Wash load	Suspended ld	wash ld
Suspended bed material ld		Bed material ld
Bed ld	Bed ld	

Rough / Midterm

15/08

Lec – 05

Forces acting in a river:

Gravity, F_g → since $AL\rho g$

Shear, FR → $\tau_0 (2d+w)L \cos\alpha$

$F_g = FR \rightarrow \tau_0 = \rho g h s$

Stream power: measure of the main driving forces acting in a channel

Determines river's capacity to transport sediment & perform geomorphic work.

Rate of energy dissipation against bed and banks per unit d/s len.

$\Omega = \rho g Q s \rightarrow \frac{\Omega}{w} = v \tau_0$ $\quad [Q = Av;\ \tau = \rho g h s]$

Flow resistance:

$v = C\sqrt{hs} \Rightarrow v = C\sqrt{\tau/\rho g}$

$\Rightarrow \tau \propto v^2$

$\Omega = \rho g Q s = \rho g w h v s = \tau w v \approx w v^2 v$

$\Rightarrow \Omega \propto v^3$

Stricklen's equation: $n = 0.047\, d_{50}^{1/6}$

Sediment movement:

Competence: Largest grain (dia) a stream is capable of transporting.
Capacity: Maximum amount of sediment of given size a stream can transport.
Fall velocity: Avg vel. that a particle would attain if falling alone in infinit extent of water at 24 °C.

Basic mechanism of sediment transport:

Depends on the balance between:

i) Gravity pulling ↓
ii) Drag & lift force trying to suspend or move d/s

Threshold of movement:

i) Lift force > grav force
ii) Drag force > combined grav. & frictional force
iii) Fluid forces moment > grav. forces moment

Gravitational force = $(4/3)\,\pi\,(d/2)^3\,(\rho_s - \rho)\,g$ [mass * grav.]

$F_g = (\pi/6)\,d^3\,(\rho_s - \rho)\,g \rightarrow F_g \sin\alpha$

Drag force, $F_d = C_d\,(\frac{\rho u^2}{2})\,A = C\tau A$; C_d → drag coeff, C → combined coeff.

Lift force → negligible

Initiation of movement:

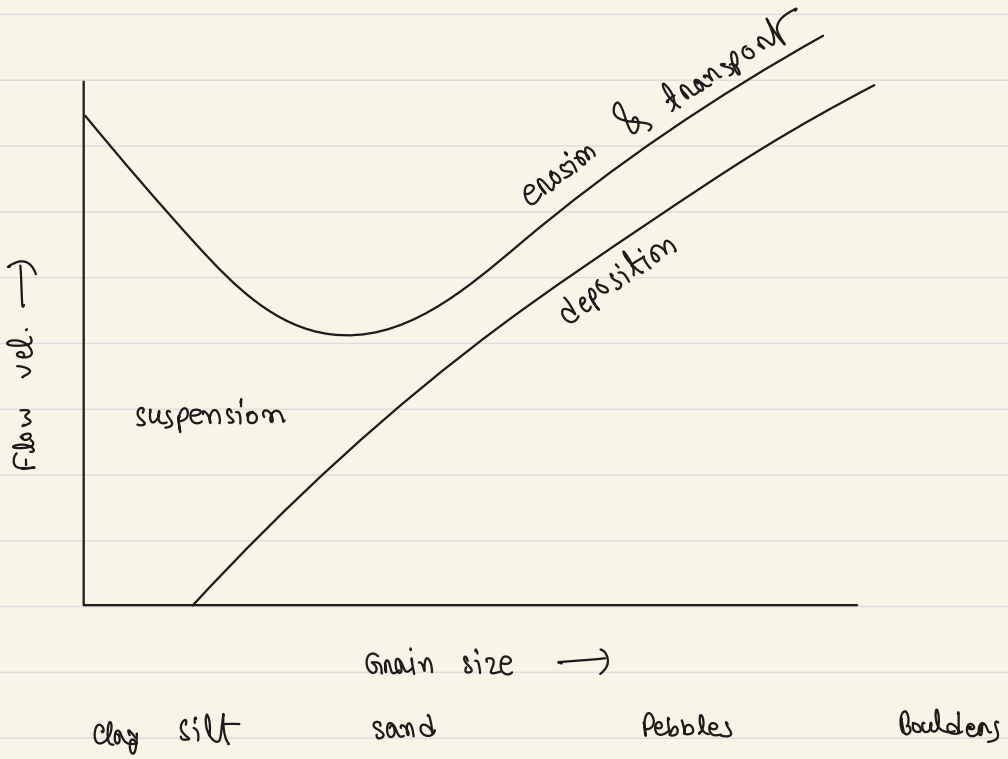
$$F_D + F_L > F_g \rightarrow F_D > F_g$$

Through simplifications,

$$\tau_c = \tau^* d (\rho_s - \rho) g \; ;$$

$\tau_c \rightarrow$ critical shear stress

$\tau^* \rightarrow$ shield's paraam



Shield's param :

- Highest for fine textured soil | (0.029, 0.250]
- Lowest for sand | [0.109, 0.029)
- Increases to a const for coarse textured soil | 32 mm, 0.05
  2048 mm, 0.054
  ↳ 0.06

$$\tau_c = \tau^* d g (\rho_s - \rho)$$

considering, larger d, $\tau^* = 0.06$

quartz, $\rho_s = 2650 \text{ kg/m}^3$

$$\tau_c = 970 d$$

P21/ $h = 0.3\ m$

$s = 1/1000$

$d = 1\ mm$

$\tau^* = 0.035$

$\tau_c = \tau^* dg(\rho_s - \rho)$

$= 0.035 \times 1 \times 9.81 (2650 - 1000) = 0.57\ N/m^2$

$\tau = \rho g h s$

$= 1000 \times 9.81 \times 0.3 \times 1/1000 = 2.94\ N/m^2$

$\because \tau > \tau_c \rightarrow$ would move/erode

P22/ $w = 55\ m$ $C = 32$

$d = 10\ mm$ (gravel)

$s = 0.005$

$\tau_c = 970 d$

$= 970 \times 0.01 = 9.7\ N/m^2$

$\tau = \rho g h s = 9.7$

$\Rightarrow 1000 \times 9.81 \times h \times 0.005 = 9.7$

$\Rightarrow h = 0.198\ m$

$\therefore Q = Av$

$= 55 \times 0.198 \times 1 \therefore 10.89\ m^3/s$

$[v = C\sqrt{hs} = 32\sqrt{0.198 \times 0.005} = 1\ m/s$

16/08

Lec 06

Regimes of flow:

Defn: Refers to the classification of bed and water surface that develops as flow characteristics are changed in alluvial river.

Lower flow regime:

- ripples, dunes w/ ripples superposed, dunes, washed out dunes
- $Fr < 1$
- Lower vel.
- water surface out of phase w/ bed surface
- Lower sediment transport cap.
- Large flow resistance

Upper flow regime:

- Plane bed, anti-dunes w/ standing waves, anti-dunes w/ breaking waves.
- $Fr > \sim 1$
- Higher vel
- " sediment transport cap
- Lower resistance
- water surface in sync w/ bed surface

Transitional flow regime: erratic

Bed forms w/ increasing vel:

Plane bed	→	ripples	→	dunes	→	transition	→	anti-dunes
$\tau < \tau_c$		$\tau > \tau_c$		$\tau \gg \tau_c$		Q ↑↑		Q ↑↑
$Fr < 1$		$Fr < 1$		Q ↑		$Fr < -1$		$Fr > 1$
				$Fr < 1$				

Impact of eddies:

1. Sediment transport
2. Channel roughness

Resistance to flow in alluvial river:

As long as $\tau < \tau_c$, resistance formula (manning's, chezy's) ok.
when sediment starts moving, boundary resistance changes and those formula become invalid

Roughness of moveable bed alluvial river,

Roughness = Grain roughness + Form roughness

$$K_s = K_{s1} + K_{s2}$$

Grain roughness,

$$K_{s1} = 3d_{90}$$

For gravel rivers, $K_{s1} > K_{s2}$ normally

Form roughness

$$K_{s2} = 1.1h\left(1 - e^{-\frac{2gh}{L}}\right)$$

$$f = 1.76\, d_{50}^{1/2}$$

$$K_{s2} = 0.022 f^{0.2}$$

Settling velocity of particles:

Sphericity: → $\frac{A_s}{A_p}$; $\frac{\text{area of sphere of same vol}}{\text{area of test particle}}$

Shape factor: → $\frac{c}{\sqrt{ab}}$; a → major axis

c → minor axis

b → intermediate axis

Reynold's Number, $N_{Re} = \frac{wd}{\nu}$; w = fall vel

Viscouse resistance env. ($N_{Re} < 1$):

$$w = \frac{g}{18\mu} d^2 (\rho_s - \rho) \qquad \text{(Stokes eqn)}$$

Inertial resistance env. ($N_{Re} > 1$, $d > \sim 0.2mm$):

$$w = \sqrt{\frac{4}{3} \frac{g}{C_D} \left(\frac{\rho_s - \rho}{\rho}\right) d}$$

$$C_D = \frac{24}{N_{Re}} + \frac{3}{\sqrt{N_{Re}}} + 0.34 \qquad \text{(Drag coeff.)}$$

N_{Re}	C_D	w
< 1	$\frac{24}{N_{Re}}$	$\frac{g}{18\mu}(\rho_s - \rho)d^2$
$1 - 3000$	$\frac{24}{N_{Re}} + \frac{3}{\sqrt{N_{Re}}} + 0.34$	$\sqrt{\frac{4}{3}\frac{g}{C_D}\left(\frac{\rho_s - \rho}{\rho}\right)d}$
> 3000	044	$\sqrt{\frac{4}{3}\frac{g}{C_D}\left(\frac{\rho_s - \rho}{\rho}\right)d}$

Non-spherical particles:

$$R_e = \phi \frac{w d}{\nu}$$

$$w = \sqrt{\frac{4}{3}\frac{g}{\phi C_D}\left(\frac{\rho_s - \rho}{\rho}\right)d}$$

P36/ $d = 1\ mm = 0.001\ m$

$\phi = 0.90$

$S.G = 2.1$

$\nu = 1.003 \times 10^{-6}\ m^2/s$; $\mu = \rho\nu = 10^3 \times 1.003 \times 10^{-6} = 1.003 \times 10^{-3}\ kg/ms$

Using stokes law:

$$w = \frac{g}{18\mu}(\rho_s - \rho)d^2$$

$$= \frac{9.81}{18 \times 1.003 \times 10^{-3}}(2100 - 1000)\,0.001^2 = 0.598$$

$$\therefore N_{Re} = \phi\frac{wd}{\nu} = 0.9 \times \frac{0.598 \times 0.001}{1.003 \times 10^{-6}} = 537 \quad [>2 \text{ \& } <3000]$$

Trial & error:

Initially, $N_{Re} = 537$

$$C_D = \frac{24}{N_{Re}} + \frac{3}{\sqrt{N_{Re}}} + 0.34$$

$$= \frac{24}{537} + \frac{3}{\sqrt{537}} + 0.34 = 0.514$$

$$\therefore w = \sqrt{\frac{4}{3}\frac{g}{\phi C_D}\left(\frac{\rho_s - \rho}{\rho}\right)d}$$

$$= \sqrt{\frac{4}{3}\frac{9.81}{0.9 \times 0.514}\left(\frac{1100}{1000}\right) \times 0.001}$$

$$= 0.176\ m/s$$

w	N_{Re}	C_D	w
0.598	537	0.514	0.176
0.176	157	0.732	0.148
0.148	132	0.783	0.143

$\therefore w = 0.143$ m/s

Estimation of sediment transport rate

$w = f(d^{1/2}, C_D) \rightarrow L/T$

$\tau = \rho g h s$

$\tau_c = \tau^* g d (\rho_s - \rho)$

$\tau/\rho = ghs = \frac{L}{T^2} \times L \times C$

$= \sqrt{\frac{L^2}{T^2}} = \frac{L}{T} = U_*$ ← shear velocity

$\frac{w}{U_*}$ ← determines whether particle stay in suspension or falls
← which dominates

$q_s = \int C u \, dy$ ← both logarithmic; diff. to int.

close to surface, conc. low

small at top

very small; a close to bed

Simplified: $\frac{C}{Ca} = \left[\frac{(D-y)}{y} \frac{(a)}{(D-a)}\right]^{Rn}$ [memo]

$R_n = w/ku_*$; $k = 0.4$

only limitation: at $y = D$, $C = 0$ [not true]

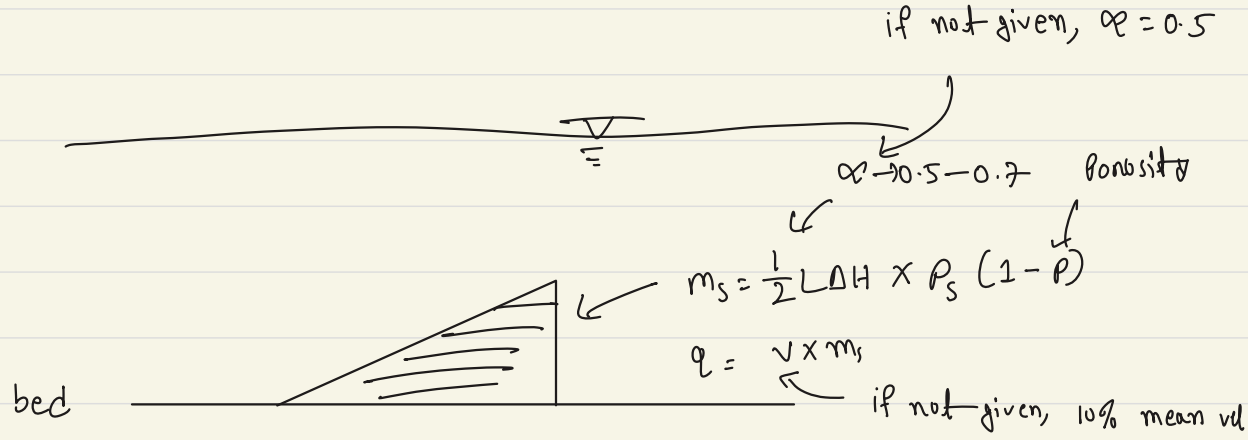
$R_n > 2.5$ → bed ld

$1.8 - 2.5$

< 1.8 → suspension

< 0.25 → wash ld

Bed load:


if not given, $\alpha = 0.5$
$\alpha \rightarrow 0.5 - 0.7$
Porosity
$m_s = \frac{1}{2} L \Delta H \times \rho_s (1 - P)$
$q = v \times m_s$
bed
if not given, 10% mean vel

Example

Estimation of bed load transport rate

Meyer-Peter:

$$q_b = 0.253(\tau_0 - \tau_c)^{3/2} \quad ; \quad \text{starts moving at } \tau_0 > \tau_c$$

Criteria for bedload transport mode

Dynamic Adjustment of River System

Lane's Relationship:

four params affecting morphology -> Q, S, d, Q_s

$$Q_s d \propto QS$$

$$Q_s \propto \frac{Q_w S}{d}$$

$$C_s = Q_s / Q_w$$

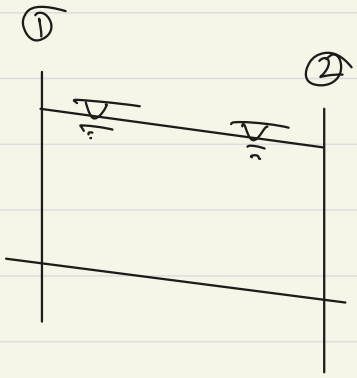
$$Q_s d \propto Q_w S \rightarrow C_s = f(S, 1/d)$$

$\uparrow Q_s d \propto \uparrow Q_s \rightarrow$ deposit u/s

$\downarrow Q_s d \propto \downarrow Q_s \rightarrow$ erosion u/s

$\uparrow Q_s d \propto \uparrow Q_s \rightarrow$ erosion u/s

$\downarrow Q_s d \propto \downarrow Q_s \rightarrow$ deposition



Three limitations:

1. Qualitative
2. No temporal / spatial
3. No planform

Quantitative:

$$a(b/c)^{1/3} = de$$

Example:

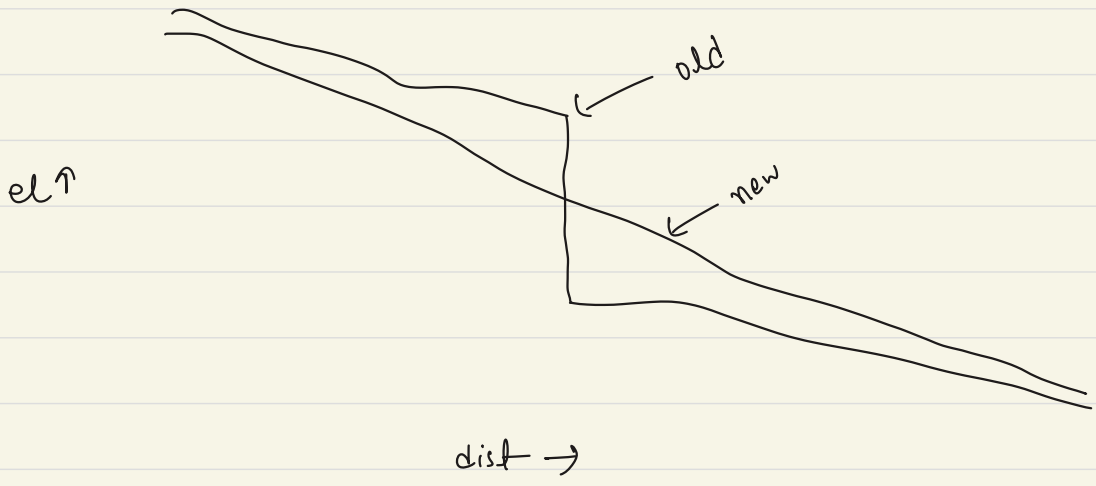
Calculation → 3/4 mark (of 10)
Explain → rest

Q ↓ → power ↓
Can't transport same sediment
Aggredation
slope inc.

[diversion intake water from top; Q_s don't chng much]

Response of a river to sudden vert. faulting

slope ↑ → sediment ld ↑ erosion ← u/s
slope ↓ → deposition ← d/s



L11 23/08

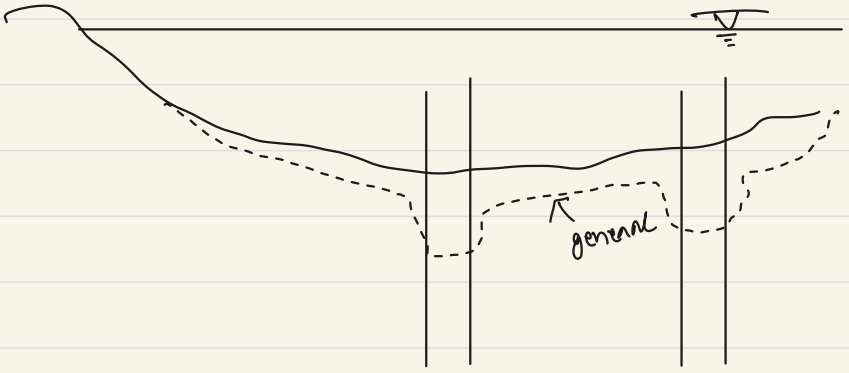
River Scour

Scour → smaller → hours to day; few meters to hundred meters
↳ opposite/similar term → degradation
↳ days, month, years; several hundred km

→ generally due to man-made struct / human intervention
→ " " " natural

Total scour: General scour ← regardless of struct.
Localized scour ← due to struct
↳ ...

↳ aggradation
degradation



Contraction scour:

Due to bridge on constricted section
on on the whole section due to piers

Can go for constricted bridge new vel within limit.

Scour at cylindrical pier

Factors affecting magnitude of local scour

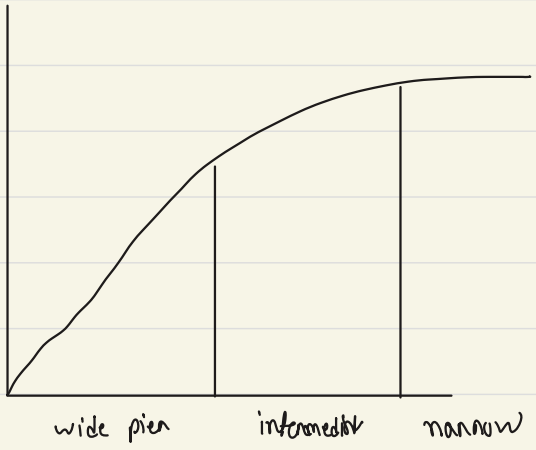
velocity → $\Omega \propto v^3$

$d_s \propto (v/v_c)^n \times D(\gamma)$; $v_c \leftarrow$ critical vel

Flow depth & pier widths

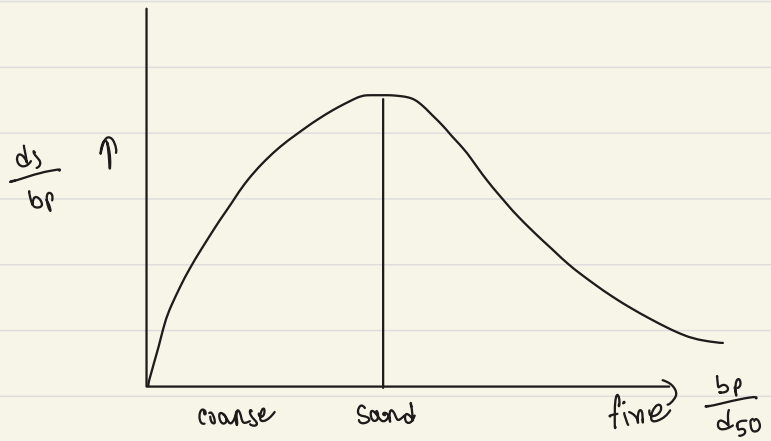
$y_1/b_2 \lesssim 0.2$ ← wide pier → $d_s \propto y$

$y_2/b_1 \gtrsim 1.4$ ← narrow pier → $d_s \propto b_p$



Grain size:

Sand: 0.06 – 2 mm



L12 25/08

River scour

Effect of pier shape:

least 

most 

Effect of angle of attack

$\theta \uparrow \rightarrow$ scour $\uparrow$

$L/B \uparrow \rightarrow$ " $\uparrow$

Abutment scour

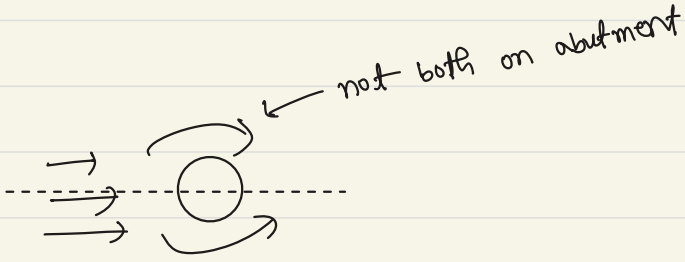
less than pier scour

→ v ↓

→ wake vortex

→ not verticle (tapered)

→ resistance from river bank



Clear water scour

↓

no erosion

not carrying sediment

vel not enough

Live bed scour

↓

bed forms

vel ↑

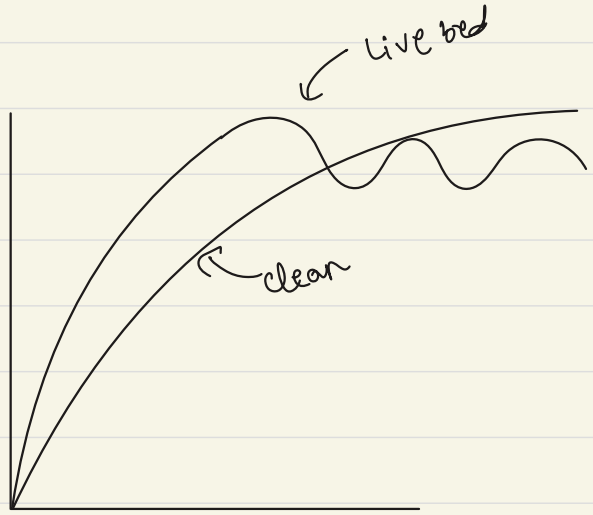
around 10% lt clear water scour

L-13 02/09

CT -> next sunday
before today's topic

River scour

Cln / Live bed scour



$$v_c = 10.95\, y_1^{1/6} d_{50}^{1/3}$$

However, we already know v_c from $\tau > \tau_c$

Use this when local obstruction (pier) is placed

Est. of scour depth

Normal & complex pier:

why complex always: slender col; buckles $\frac{L}{d} > 12$

DL, LL
wind
wave (from ship)

complex → normal equiv.
with larger dia

$$\gamma_s = \gamma_{pier} + \gamma_{pile_cap} + \gamma_{pile}$$

y = depth of flow
b = pile dia
d_s = est. depth of scour
Y = depth of cap top from bed

Case 1: pile cap completely below est. scour depth
normal pier

Case 2: pile cap partially above est. scour depth —
normal pier
even may be less scour once exposed since it intercepts vortex eff. on soil

Case 3, 4: consider complex convert to equiv. dia } scour of all three scours

$$b_e = b\left(\frac{d+Y}{d+b^{\varnothing}}\right) + b^{\varnothing}\left(\frac{b^{\varnothing}-Y}{b^{\varnothing}+d}\right)$$ [memo]

↗ equiv. dia

E.g., $\frac{d_s}{b_p} = 2.5$ ← use b_e for complex

calc. d_s from all formulas (7) then take the maximum

Good → Richardson

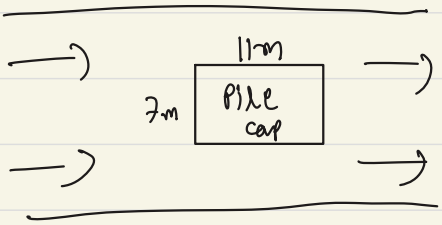
But still consider all

Example: V_n may not be directly given (discharge) on hydraulic depth

$$Y_s = 2\,K_1K_2K_3K_4\left(\frac{d}{Y}\right)^{0.65} F_{n_1}^{0.43}$$

Pile cap

use width (7m)



Lacey - Inglis method:

no longer used

traditionally was used → Lacey → $D_{LG} = 0.47 \left(\frac{Q}{f}\right)^{1/3}$

Inglis → $D_{se} = 1.2 D_{LG}$

e.g., 20

considers depth of design flood lvl

Example

Scour protection:

(a) Armoring countermeasures
(b) Flow altering "

Collar, sacrificing pile

Case study

Richardson matches the most w/ obs.
but lots of uncertainties

Rough / CT-3 05/09

Estimation of sediment transport rate

Force of water → $\tau = \rho g h s$

Critical → $\tau_c = \tau^* d g (\rho_s - \rho)$

$$w = \sqrt{\frac{4}{3} \frac{g}{C_D} \frac{\rho_s - \rho}{\rho} d} \quad ; \quad C_D = \frac{24}{N_{Re}} + \frac{3}{\sqrt{N_{Re}}} + 0.34$$

$\tau > \tau_c \rightarrow$ bed moves

$\tau/\rho = ghs = \frac{L}{T^2} L C$

$= \frac{L^2}{T^2}$

$\Rightarrow \sqrt{\tau/\rho} = \frac{L}{T} \rightarrow$ velocity

$\rightarrow u^*$

$u^* \rightarrow$ shear vel.

$w \rightarrow$ fall vel.

$\frac{w}{u^*} \rightarrow$ determines whether particle stay in motion or fall

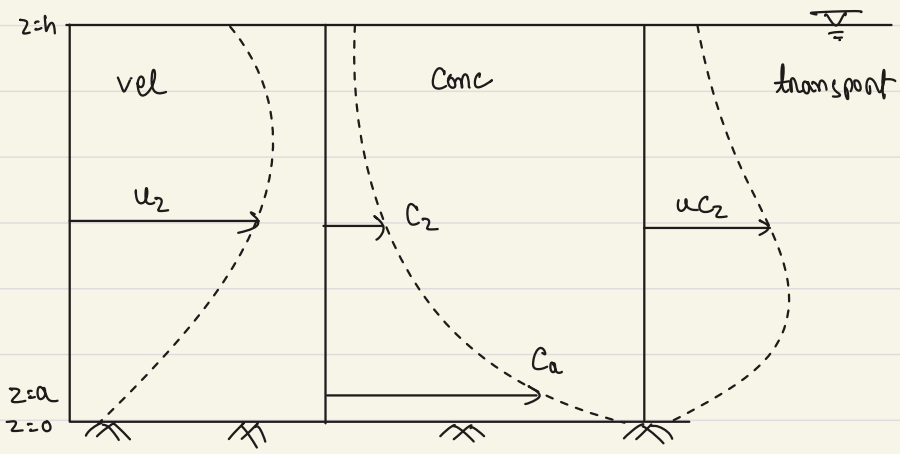
$w \rightarrow$ falls

$u^* \rightarrow$ moves

Sediment load is product of vel. & conc.

logarithmic; complex to int.

$q_s = \int c u \, dy$



Appx. suspended sediment conc.

$$\frac{C}{C_a} = \left[\frac{(D-y)}{y}\,\frac{a}{(D-a)}\right]^{R_n}$$

$R_n = \frac{w}{Ku^*}$; $K = 0.4$

a = very close to bed

fraction val

upper half

↳ [small × small]^n → very small

conc. close to surf. is low

lower half

↳ [less small × small]^n → of. surface

Limitation: $y = D \rightarrow C = 0 \rightarrow$ not true

Rouse Number:

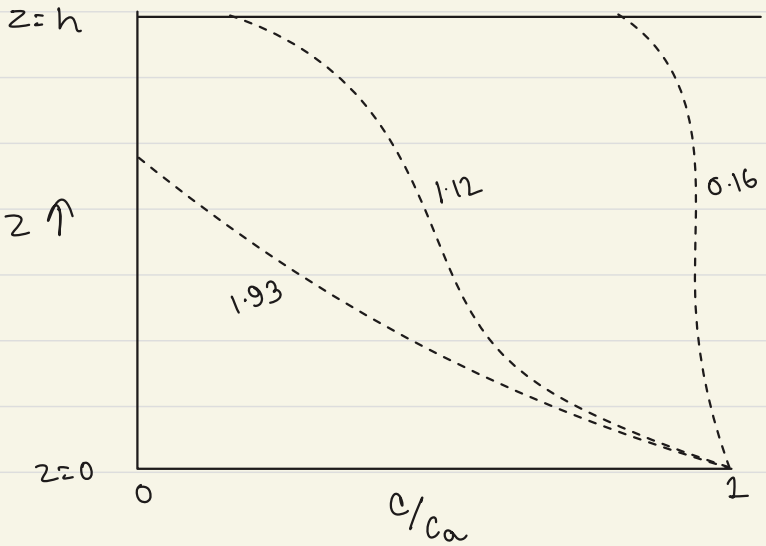
$$R_n = \frac{w}{Ku^*}$$

$R_n > 2.5$ → bed load

$1.8 < R_n < 2.5$ → in transition; can be bed ld / suspended ld

$R_n < 1.8$ → full suspension

$R_n \leq 0.25$ → wash ld



P12/ $D = 4m$

$S = 2.25 \times 10^{-4}$

$d_{50} = 0.4m$

$w = 0.04$ m/s

$a = 0.4m$, $C_a = 400$ ppm

$$R_n = \frac{w}{K u^*} \qquad u^* = \sqrt{\frac{\tau}{\rho}} = \sqrt{ghs}$$

$$= \frac{0.04}{0.4\sqrt{0.008829}} \qquad = \sqrt{9.81 \times 4 \times 2.25 \times 10^{-4}} \text{ m/s}$$

$$= 1.06 \quad \text{[full suspension]} \qquad = \sqrt{0.008829}$$

$$\frac{C}{C_a} = \left[\frac{D-a}{a} \quad \frac{a}{D-a}\right]^{R_n}$$

$$\Rightarrow \frac{C}{400} = \left[\frac{4-1}{1} \quad \frac{0.4}{4-0.4}\right]^{1.06} \Rightarrow C = 124.83 \text{ ppm}$$

To become bed load:

$$R_n > 2.5 \Rightarrow \frac{w}{K u^*} > 2.5$$

$$\Rightarrow w > K \times \sqrt{ghs} \times 2.5$$

$$\Rightarrow w > 0.4 \times \sqrt{9.81 \times 4 \times 2.25 \times 10^{-4}} \times 2.5$$

$$\therefore w > 0.094 \text{ m/s}$$

Suspended ld:

$$Q_s = C_0 Q \; ; \qquad C_{av} = R^{1/2} S^{2/3}$$

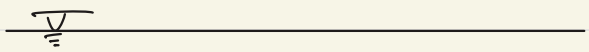
Bed load:

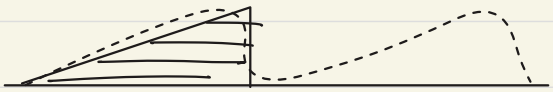
10% of v_{mean}

$$q_b = v\, m_s$$

$$m_s = 1/2 \, L \, \Delta H \times \rho_s (1-\rho)$$

$$\therefore q_b = v \times \alpha \, L \, \Delta H \, \rho_s (1-\rho) \; ;$$





$\alpha = 0.5 \sim 0.7$

$\rho_s = 2650 \; kg/m^3$

$\rho = 0.5$ (Porosity)

$[q_b \approx 1 - 10\% \text{ of } Q_s]$

#P14/ $W = 160 m$

$n = 0.023$

$D = 2.2 m$

$S = 0.08/100$

Dunes: $L = 80 cm$

$H = 15 cm$

$v = 10\%$ of v_{mean}

$\rho = 0.5$

$$V_m = \frac{1}{n} R^{2/3} \sqrt{S} = \frac{1}{0.023} \times 2.2^{2/3} \sqrt{0.08/100}$$

$$= 2.08 \, m/s$$

$$\therefore v = 0.3 \times 2.08 = 0.624 \, m/s$$

$$\therefore q_b = v \times \frac{1}{2} L \, \Delta H \, \rho_s (1-\rho) = 49.61 \; kg/s/\text{width}$$

$$= 7937 \; kg/s$$

Meyer – Peter & Muller eqn:

$$q_b = 0.253 (\tau_0 - \tau_{cr})^{3/2}$$

$\tau_0 = \rho g h s$

$\tau_{cr} = \tau^* d g (\rho_s - \rho)$

$970 d$

Ex P15/

$W = 50\ m$

$h = 2.5\ m$

$S = 0.0015$

$d_{50} = 3.2\ cm$

$\tau_0 = \rho g h s = 36.79\ N m^{-2}$

$\tau_{cr} = 970 d_{50} = 31.04\ N m^{-2}$

$q_b = 0.253 (\tau_0 - \tau_{cr})^{3/2} = 3.49\ kg/sm$

$\therefore Q_b = 3.49 \times 50 = 174.42\ kg/s$

Sediment transport rate of total ld :

Suspended ld → 80 – 90%

Total → suspended (1+x)

Dynamic adjustment of river system — Lane's

$Q_s d \propto Q s$

- Q → slope
- water discharge
- particle dia
- sediment discharge

$Q_s \propto \frac{Qs}{d}$ → stream power $(\Omega = \rho g Q s)$

Sediment ld, $C_s = \frac{Q_s}{Q_w}$

From Lane's, $C_s = f(s, 1/d)$

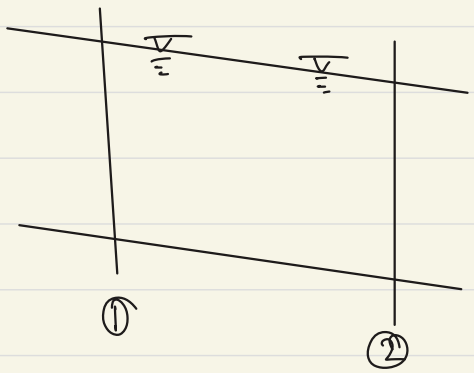
Limitation: qualitative; not quantitative
no temporal component
doesn't address planform / cross section geo

$Q_s \uparrow d \propto Q s \uparrow$ → deposition u/s

$Q_s \downarrow d \propto Q s \downarrow$ → erosion u/s

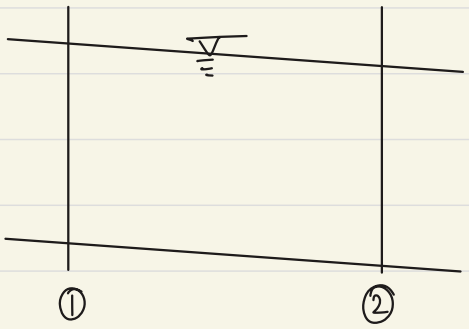
$Q_s \uparrow d \propto Q s \uparrow$ → erosion u/s

$Q_s \downarrow d \propto Q s \downarrow$ → deposition u/s



Quantitative:

$$a\left(\frac{b}{c}\right)^{1/3} = de$$



$a \rightarrow \frac{Q_{s2}}{Q_{s1}}$

$b \rightarrow \frac{d_2}{d_1}$

$c \rightarrow \frac{Y_2}{Y_1}$

$d \rightarrow \frac{Q_2}{Q_1}$

$e \rightarrow \frac{s_2}{s_1}$

Ex. P09/

$d = 0.9$

$a = 0.99$

$b = 1$

$c = 0.95$

$$a\left(\frac{b}{c}\right)^{1/3} = de$$

$\Rightarrow e = 1.12$ [slope inc.]

Explanation: $Q_s d \propto Q_s$

As Q is decreased, stream power is desc.
river can no longer transport the sediment it used to.
Hence, deposition @ u/s.

Aggradation & Degradation

Degradation: General lowering of bed lvl

↓ when ld < capacity → excess sediment is needed

d/s of dam

Armouring → bed becomes coarser as bed degrades until sufficiently thick to prevent further degradation.

Aggradation: Riverbed rise

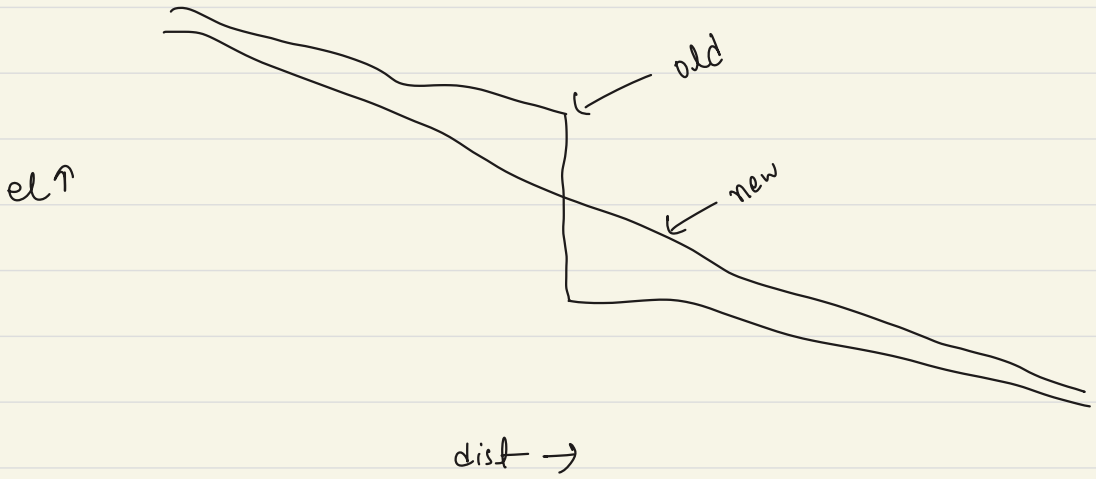
↓ ld > capacity

u/s of dam

Response of a river to sudden vert. faulting

Slope ↑ → sediment ld ↑ erosion ← u/s

slope ↓ → deposition ← d/s



Aggradation v. degradation

1.	incn. in bed lvl	dec. in bed lvl
2.	in sediment driven river	in sediment deficit river
3.	deposition	erosion
4.	dec kinetic energy	inc. kinetic energy

---

both cont. over long time & dist.

River scour

Result of erosive action of flowing water.

- General scour → regardless of hydraulic struct.
- Localized scour → due to " "
  - Aggradation
  - Degradation
  - Contraction scour → due to constriction of flow
  - Local scour → around piers / abutments

Total scour = gen + local + contraction scour

Mechanics of local scour:

Formation of vortices at base

Horseshoe vortex: pile up of water on the u/s face of obstruction and subsequent acceleration around the nose of pier

Wake vortex: vertical vortices d/s of pier.

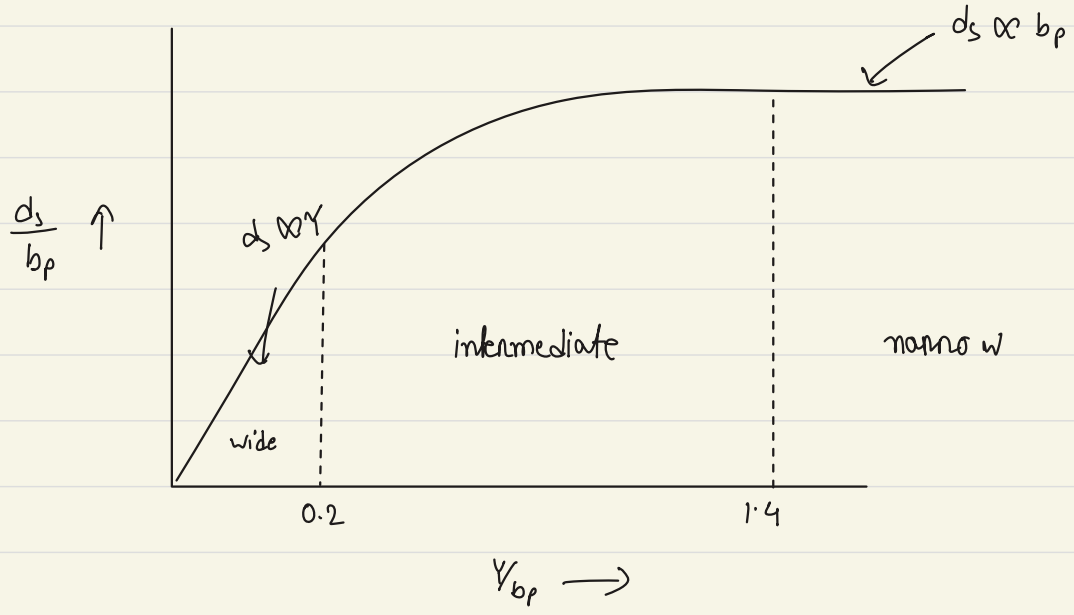
Factors affecting scour depth:

velocity: $d_s \propto \left(\frac{V}{V_c}\right)^n \times D(\alpha)$

Depth of flow & pier width:

$Y/b_p \leq 0.2 \rightarrow$ wide pier $\rightarrow d_s \propto Y$

$Y/b_p \geq 1.4 \rightarrow$ narrow pier $\rightarrow d_s \propto b_p$

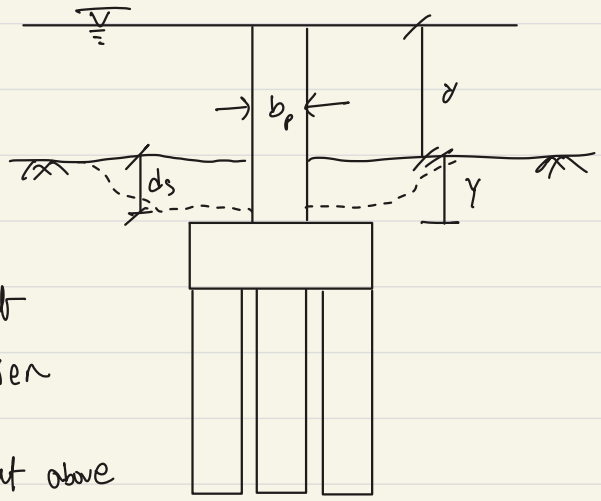


Rough / Potential Pop 09/09

Why complex pier:

1. Structural robustness: wide pile cap, slender column, pile groups carry vert. & hor. ld to deep soil.
   - DL, LL
   - wind ld
   - wave action
2. Normal pier can't reach deep stable bedrock
3. Ship collision protection
4. Seismic resistance.

Four cases:



1. top of pier cap below scour depth → normal pier
2. top of pier cap below bed but above scour depth → normal pier
3. pier cap is below surface but above bed — complex
4. pier cap is at or above water surface → complex

Eff. pier dia:

$$b_e = b\left(\frac{d+\gamma}{d+b^{**}}\right) + b^{**}\left(\frac{b^{**}-\gamma}{b^{**}+d}\right)$$

Fsd. scour depth:

$$\frac{Y_s}{Y_1} = 2.0 \times K_1 K_2 K_3 K_4 \left(\frac{a}{Y_1}\right)^{0.65} Fr_1^{0.43}$$

Scour protection:

1. Armoring counter-measures → withstands the increased erosive force → riprap, concrete blocks, geo bags, etc.

2. Flow altering counter-measures → reduces erosive force.
   → collars, sacrificial piles.

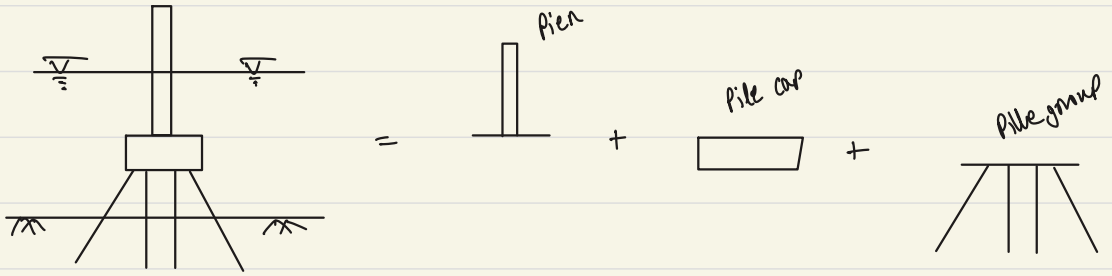
Collars: thin protective disc made of steel/concrete placed around pier at closer to bed.
deflects down flow vortex.

Sacrificial piles: Piles of small dia are placed u/s of piers. The suppress the approaching flow, reducing force and velocity.

why not in BD: cost
extreme scour depth (60m+)

BD uses → deep piling, riprap, geo bags, concrete blocks

Components of complex pier:



$$\gamma_s = \gamma_{pier} + \gamma_{pc} + \gamma_{pg}$$

Eff. of dredging



S ↑ w.n. to u/s → Ω ↑ → erode

S ↓ w.n. to d/s → Ω ↓ → deposit

River training / Bank protection

- Transverse → active → perpendicular to flow
- Longitudinal → passive → along bank

Another way to classify:

- Hard core → man-made, rigid
- soft core → natural, not-rigid; e.g., vegetation
  - ↳ not immediate sol^n; major lim

↳ can be transverse / longitudinal

Slack zone

adv. not only protect bank
but also build a new bank through sedimentation (reduced flow)

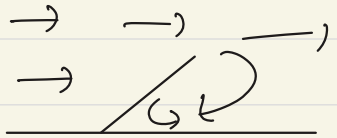
Spurs : Plan view → permeable, impermeable

min 3

much less ← exp.

Flu. view → submerged, non-submerged

Orientation → attracting, deflecting, repelling



↓

basically to maintain a
deeper section

e.g. jetty

Shape → I, circulary, L, T, ...

smooth deflect

higher scour

Design ; skip (mostly) (not num-math)

Guide bank:

- - -

Launching apron (unique to guide bank)

Struct prov. in case of a emergency that is going to fall

- - -

Porcupine:

Two shapes → Tetrahedral
Prismatic

Revetment

3 profiles (WL) → standard Low water
High "
Highest Flood Level

rip-rap, ∈ Revetment
gabions

Two types → open joint, closed joint
see lec notes

SHW — SLW
open type
poor water pres.

SHW - HFL
closed type

Rip-rap — large size rock → 30 cm dia

Gabions — small " " → 8 to 20 cm dia (in cage)

stackable

Concrete blocks → $300mm^2 - 400\,mm^2$

Geo-bags → flexible

are transported and fallen into exact posn. w/ GPS

Softcone . . . 30% less exp.

Mangrove → root

Bandals not only protect bank, but develops

W13 16/09

Final → lots of theories
figure where possible

total 5 ques

Navigation

Navigable water — deep enough, calm enough, wide enough

Adv. — . . .

. . .

Cost
Carbon emission
Energy eff.

Delay → move water as opposed to air for land modes
↳ transshipment process (fast. → large ship → small ship → ...)

Draft → part of vessel under water
keel → more is bttn

Depth →
width → two vessels

Blockage factor
Flow vel
No helical current

Morphological factors
Flow fact.

Navigation lock
Canalization } not done on Bangladesh

cut offs for navigation Oxbow lake by dredging

Dredging

Hydraulic, cutting
Two types — capital, maintenance
Process

Navigation states of Bangladesh

Dredging in Bangladesh

Eff.

EOL

Flood of Jamuna around June
Ganges July
Coincided on 1998

Rough/ Final 20/10

Lec 1

Streams → channelized flows of water & sediment
Overland flow → non-channelized flows of water

Surface runoff → overland flow → streams / river

River system → collecting sys | transporting sys | dispersing sys
/ Subsystems
branches | trunk | roots
tributaries | distributaries

Freshwater flow: 1st order | 2nd order | 3rd order | 4th order
Rivulet | Creek | Stream | River

Zones → erosional zone | transport zone | depositional zone
degradation | equilibrium | aggradation
steep | mild | flat
cobble | sand | silt

Levee → elevated area beside river bank
Floodplain → riverbank adjacent area that is flooded twice in three years.
Thalweg → imaginary line connecting the deepest points along longitudinal profile of river.

Estuaries → less river ld and sediment ld;
Delta → large " " " " "

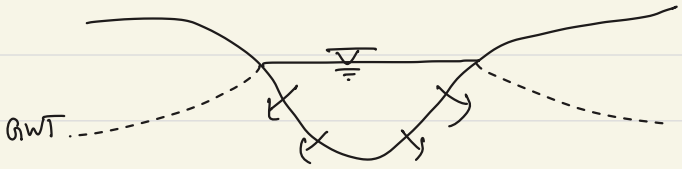
River classification:

Based on substrate: The bed on which river flows

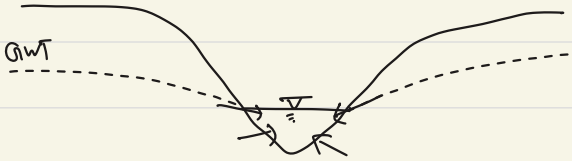
1. Bed-rock: Small rivers, on mountainous areas, flows on immovable bed rocks. They are pretty stable.
2. Alluvial: Flows on beds and banks of mobile sediment/soil. They are formed by self deposition and erosion of bed materials. Can assume many forms based discharge, material, and sediment load. They are morphologically unstable.

Based on GWT:

1. Influent: Gives water
2. Effluent: Gains water



influent



effluent

Based on percent of time they flow:

1. Always → Perennial
2. Ephemeral → Only after rainstorm
3. Intermittent → Based on time of year/season

Based on sediment load:

1. Suspended load: Sediment source is mostly silt – clay.
   Stream is meandering with uniform width. Sinuosity > 2.
   Small bed ld (< 3% of total ld)
   Is relatively narrow; low w-d ratio; gentle slope;
   Bed and banks are relatively stable due to cohesive mats.
2. Mixed load: Straight channel with small amount of coarse sediment (3–11%). Sinuous thalweg.
3. Bed ld: Braided channel; unstable, large sediment ld & size. steep.

Based on morphology/pattern: Plan view

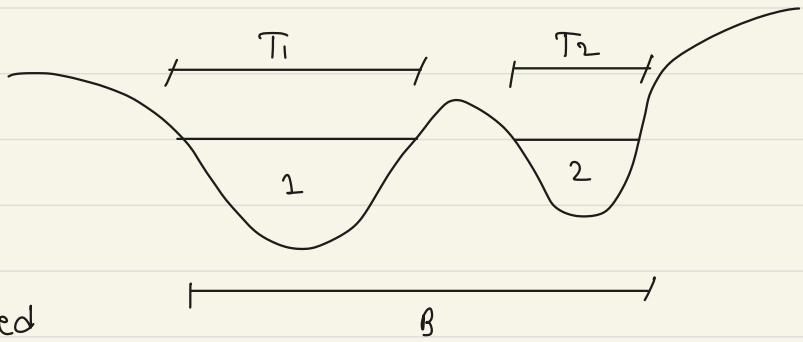
→ Sinuosity → $\frac{\text{dist of two points}}{\text{straight line dist}}$

→ multi-channeldness: Number of individual flow channel shown in a cross-section

	Single channel	Multi-channel
Low sinuosity	Straight	Braided
High "	meandering	Anastomosing

Planform Index: width used for flow to Total width

$$PFI = \frac{\Sigma T/N}{B} \times 100$$



PFI $< 3 \rightarrow$ Highly braided

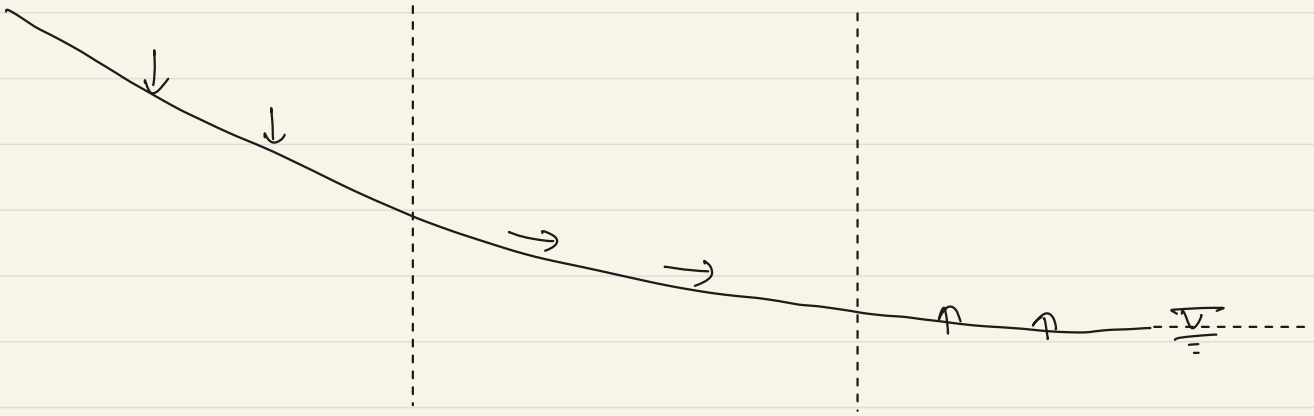
$3 - 20 \rightarrow$ Moderately "

$> 20 \rightarrow$ Low "

Changes as river goes d/s:

River

Longitudinal profile



Sediment:	Erosion	Transport	Deposition
Bed:	degradation	equilibrium	aggredation
Slope:	steep	mild	flat
Bed mat:	Cobble-gravel	gravel-sand	Sand-silt
Channel:	Confluence	Single	Branching

21/10

Defn: Tributary → a stream flowing into a larger stream

Distributary → the stream branches a river divides into, when it reaches delta.

Delta → triangular mouth of a river formed by sediment deposition

Levee / Terrace / Ridge → elevated area beside river banks.

Floodplain: area adjacent to bank that is flooded twice in three years.

Thalweg: Imaginary line connecting deepest points

Alluvial river: Bed & banks are composed of mobile sediment / soil, deposited by the river itself, and can be eroded, transported, or redeposited by flowing water.

Classify river pattern (planform; morphology):

Characteristics → sinuosity, multichannelledness

	Single	multi-channel
Low sinuosity	Straight	Braided
High "	Meandering	Anastomosing

Classification by sediment load:

Suspended ld river: Sediment sources are mostly silt, clay, or fine sand. meandering, uniform width, deep; bank stable.

Bed ld river: sources are cobble gravel; braided, unstable.

Mixed ld river: Both suspended and bed ld.

Planform Index:

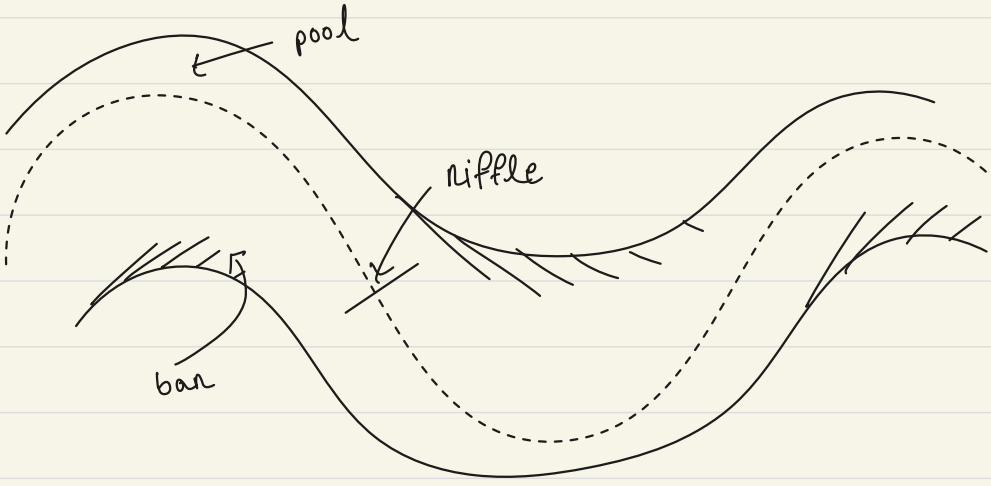
$$\frac{\Sigma \text{ avg channel width}}{\text{total width}} \times 100 = \frac{\Sigma T/N}{B} \times 100$$

21/10

Lec 2

River pattern / planform → how river looks in plan view.
Gives indication of other chars (morphologic & dynamic).
E.g., sinuous → low w/d
straight → wide & shallow

Basic patterns → straight → none, may have sinuous thalweg
meandering → bed is of cohesive mats (fine grained soil)
low discharge, sediment ld
formed by erosion of banks (pool, bar, riffle)
→ have low w/d
→ slope is gentle
→ fine grained sediment

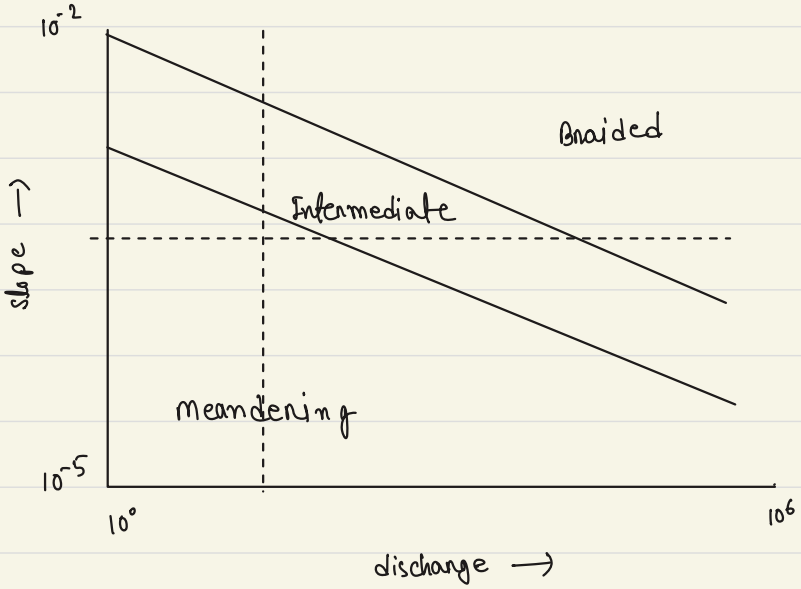


braided → bed of non-cohesive, granular mats (erodable)
high sediment ld
variable discharge, constantly changing course
mid-channel bars.

Pattern variability: variables → slope, sediment ld, sinuosity, w/d ratio

Thresholding: There's a discharge/slope above which river tends to be braided.

Effect of slope:



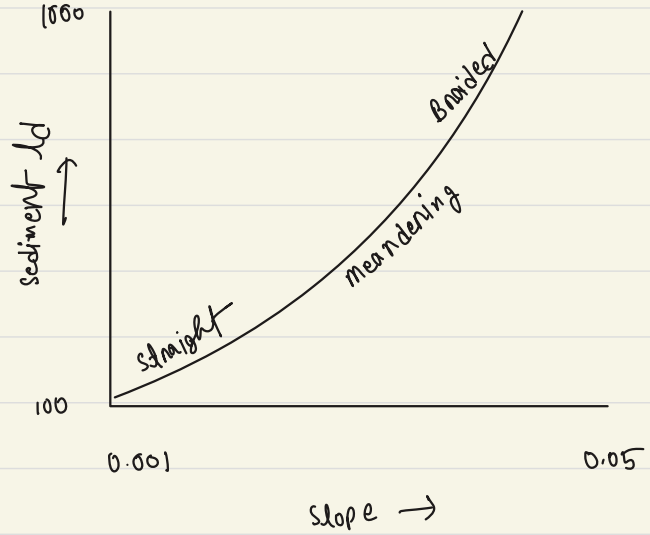
For a given discharge,

slope ↑ → straight
↓
sinous
↓
braided

For a given slope,

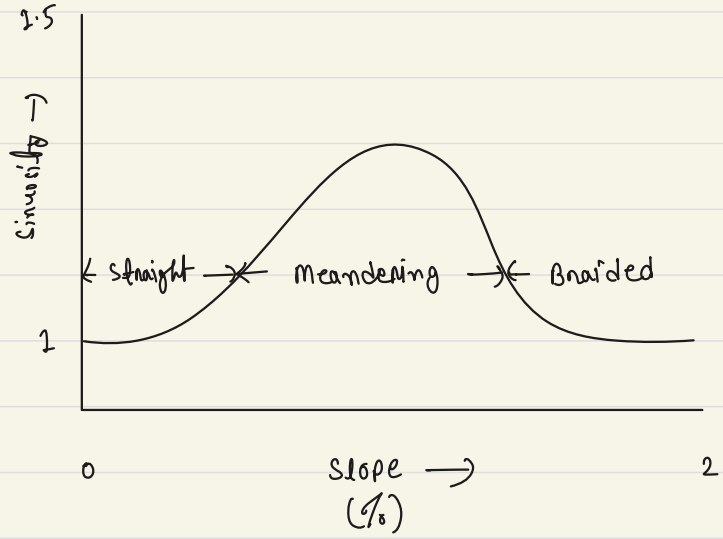
discharge ↑ → braided
(not so impactful)

Slope & sediment ld:



slope ↑ → sediment ld ↑

Sinuosity:



Slope ↑ → sinuosity ↑

within a set domain

width-depth ratio:

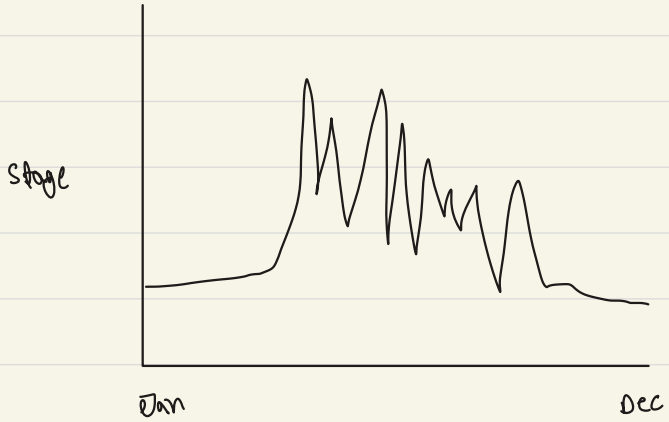


Meandering → cohesive

low w-d ratio

Classification based on flooding:

1. Normal river
2. Flashy river: Responds rapidly to rainfall (characterised by spikes in hydrograph) followed by a rapid recession within a short duration.



Common for rivers in hills / hill slopes

NE & SE region

Effect of discharge:

Discharge → w/d ratio, meander wavelength, amplitude
Slope, sediment ld → pattern and shape

Hydraulic Geometry:

$$Q = AV = wdu$$

$$w = aQ^b; \quad d = cQ^f; \quad u = kQ^m$$

$$\Rightarrow wdu = ackQ^{b+f+m} = 1 \times Q^1$$

$$\therefore ack = 1; \quad b+f+m = 1$$

At a station geometry → same station, diff time

Downstream geometry → various stations throughout longitudinal profile, same time.

P21

Discharge Q (m^3/sec)	0.2	5.9	23	39.6	74.4
Width (m)	8	12	16	18	20

$w = aQ^b$

$\Rightarrow \log(w) = \log a + b \log Q$

$Y \quad C \quad m \quad x$

From graph, $a = 8.55$, $b = 0.20$

$\therefore w = 8.55 Q^{0.20}$

From calc,

$a = 9.92$

$b = 0.16$

Given, $d = 0.4 Q^{0.45}$

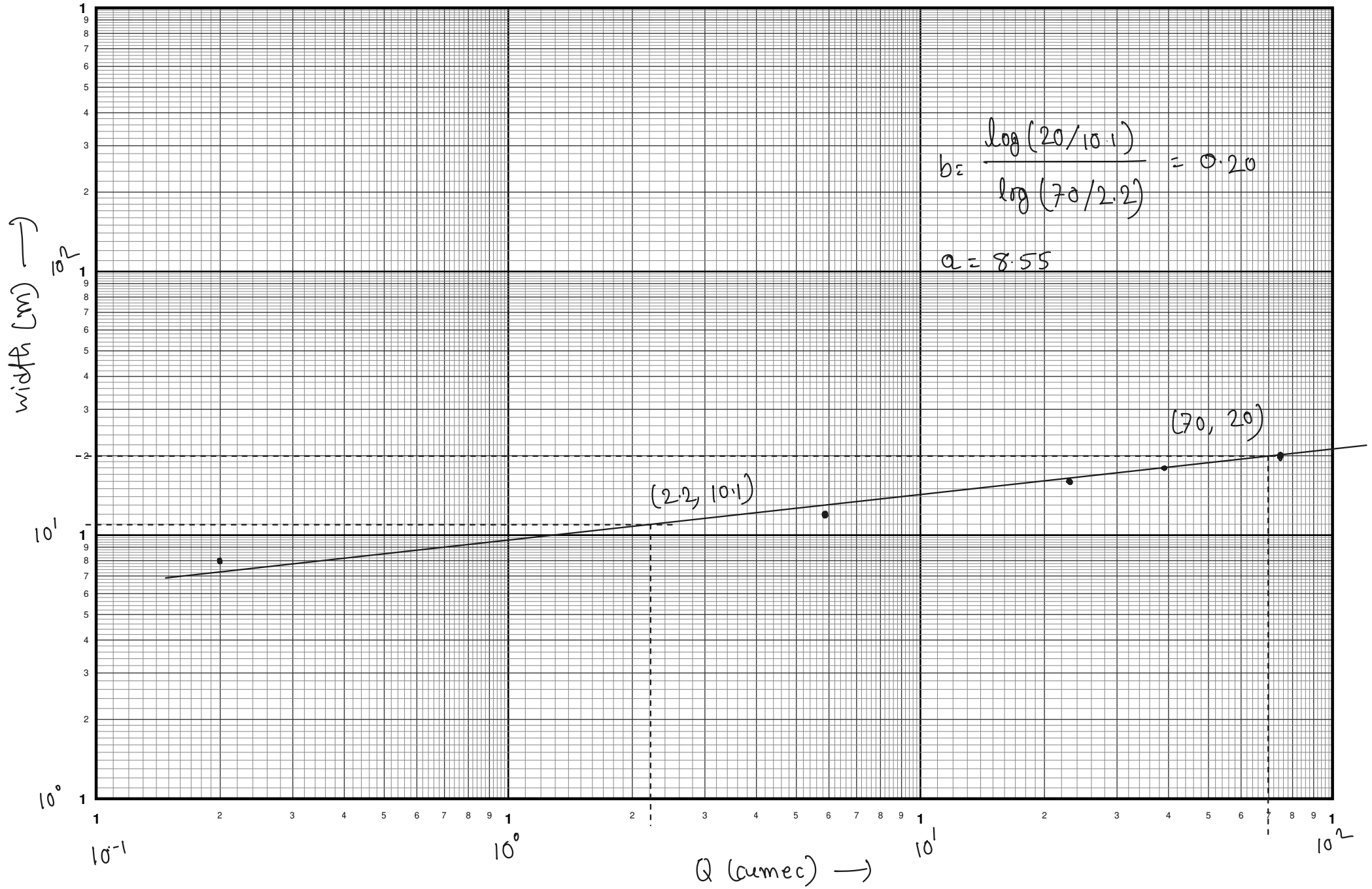
$d = kQ^m$

$m = 1 - 0.45 - 0.20 = 0.35$

$k = 1/(0.4 \times 8.55) = 0.29$

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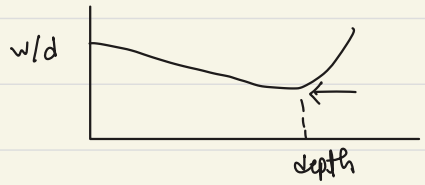
Bankfull discharge:

Flow of water just before it spills onto adjacent floodplain.
Determined by:

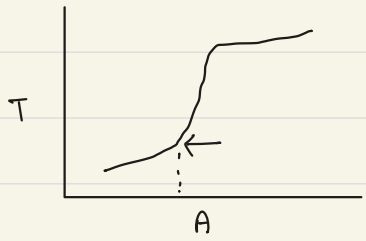
(i) w/d ratio vs. depth: normally, depth inc. faster than width

w/d ↓

sudden inc. of w cause w/d ↑



(ii) top width vs. cross-sectional area: abrupt inc. in top-widths



P23/

Depth (m)	0.4	0.9	1.1	1.4	1.8	2.2	2.3	2.5	2.8
Width (m)	9.6	11.3	13	16.1	19.8	20.9	24.2	28.8	35
W/D	24	12.6	11.8	11.5	11	9.6	10.5	11.5	

Discharge corresponding to 2.2m depth

Dominant discharge:

Bankfull discharge or discharge that is exceeded once in two years.

River slope:

Continuous decrease; $S = S_0 e^{-\alpha x}$

$$\Rightarrow Y = S_0\left(\frac{e^{-\alpha x} - 1}{\alpha}\right) \qquad \left[S = \frac{dy}{dx}\right]$$

Reason: 1. Sediment size decr. due to rolling, grinding, rubbing, crushing. Requires flatter slope to transport

abrasion
inflow
deposition

2. More discharge from tributaries; not as much sediment. Slope reduced for increased flow.
3. Deposition d/s.

Sediment size:

$$d = d_0 e^{-cx}$$

$$w = w_0 e^{-Bx}$$

Lec 3 Derived hydraulic relations

For a typical river,

$$w = aQ^{0.5} \; ; \quad d = cQ^{0.4} \; ; \quad v = kQ^{0.1} \; ; \quad s = tQ^{-1.0}$$

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

As river goes d/s, d incr. → R inc. } v ↑ } cancels out
n decr
S decr. → v ↓

velocity increases slightly.

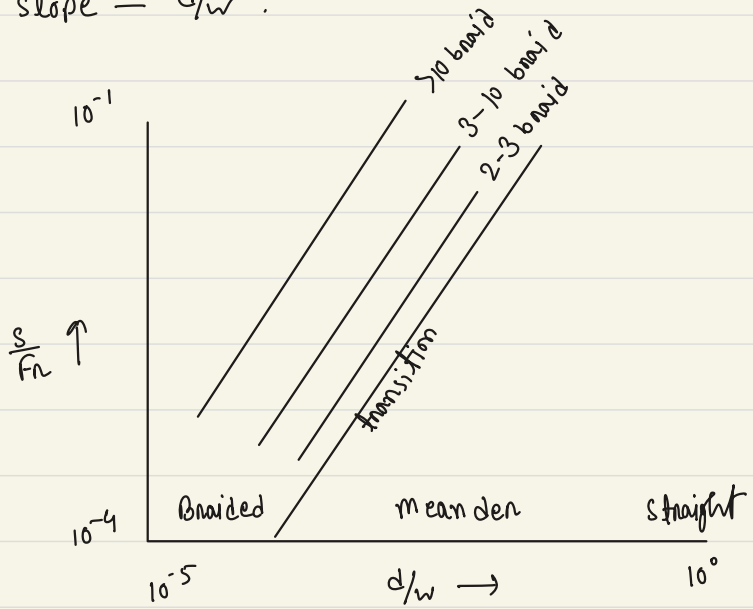
$$v = \frac{R^{2/3} S^{1/2}}{n}$$

$$\Rightarrow n = \frac{d^{2/3} s^{1/2}}{v} = \frac{c Q^{2/3 \times 0.4} \; t Q^{1/3 \times (-1)}}{Q^{0.1}}$$

$$\Rightarrow n = cQ^{-1/6} \; ; \quad n \uparrow \rightarrow Q \downarrow$$

As river goes d/s, w ↑
h ↑
v ↑
S ↓ d ↓ n ↓

slope — d/w :



w/d ↑ → braided

↓ → meander

$d/w = (w/d)^{-1}$

Meandering river hypothesis :

Coriolis force

1. Earth's rotation theory : Any object moving on Earth's surface experiences a force normal to its path, that deflects the river and results in meanders.

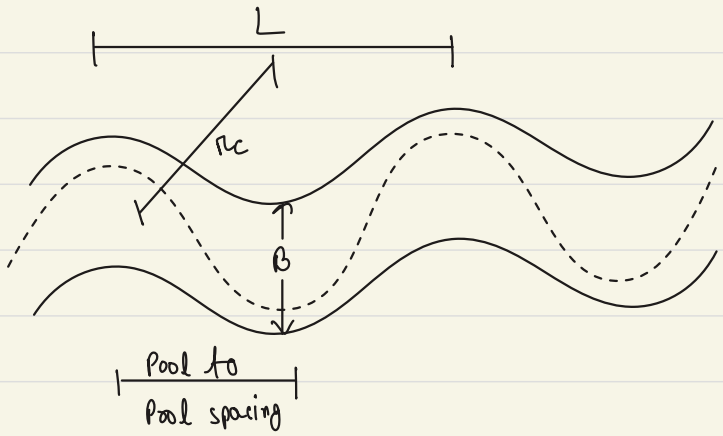
2. Disturbance theory : Any disturbance caused in a straight channel may make the flow assymetric and move towards one side more than the other — e.g., due to obsticles on sediment ld.

3. Excess energy — stretch out its path by meandering. Reduces slope.

4. General wave motion — Spatial oscillatory motion resulting in waveform similar to other natural oscillatory system — e.g., flag fluttering in wave.
Fluid flow exerts shear force on river boundaries which causes instability → fluids oscillitate.

5. Secondary current

Dimensional nlfn:



$\frac{L}{B} \approx 7$ to 10

$\frac{r_c}{B} \approx 2$ to 3

P = sinuosity

$1.5 < P < 2.0$

$W = B$

$\lambda = L$

$r_c \propto w_{bf}^{x}$

$\lambda \propto r_c \quad (\text{or} \propto w_{bf}^{x})$ } Meander len direct func of width or radius

$\lambda \propto (w_{bf} d_{bf})^{y}$ → not direct w/ depth

P18/

Width (m)	10	20	25	30	40
Spacing (m)	50	100	120	250	300

Pool to pool spacing → $L/2$

$\lambda = a w^{b}$

$\Rightarrow \underbrace{\log \lambda}_{Y} = \underbrace{\log a}_{C} + \underbrace{b}_{m} \underbrace{\log w}_{X}$

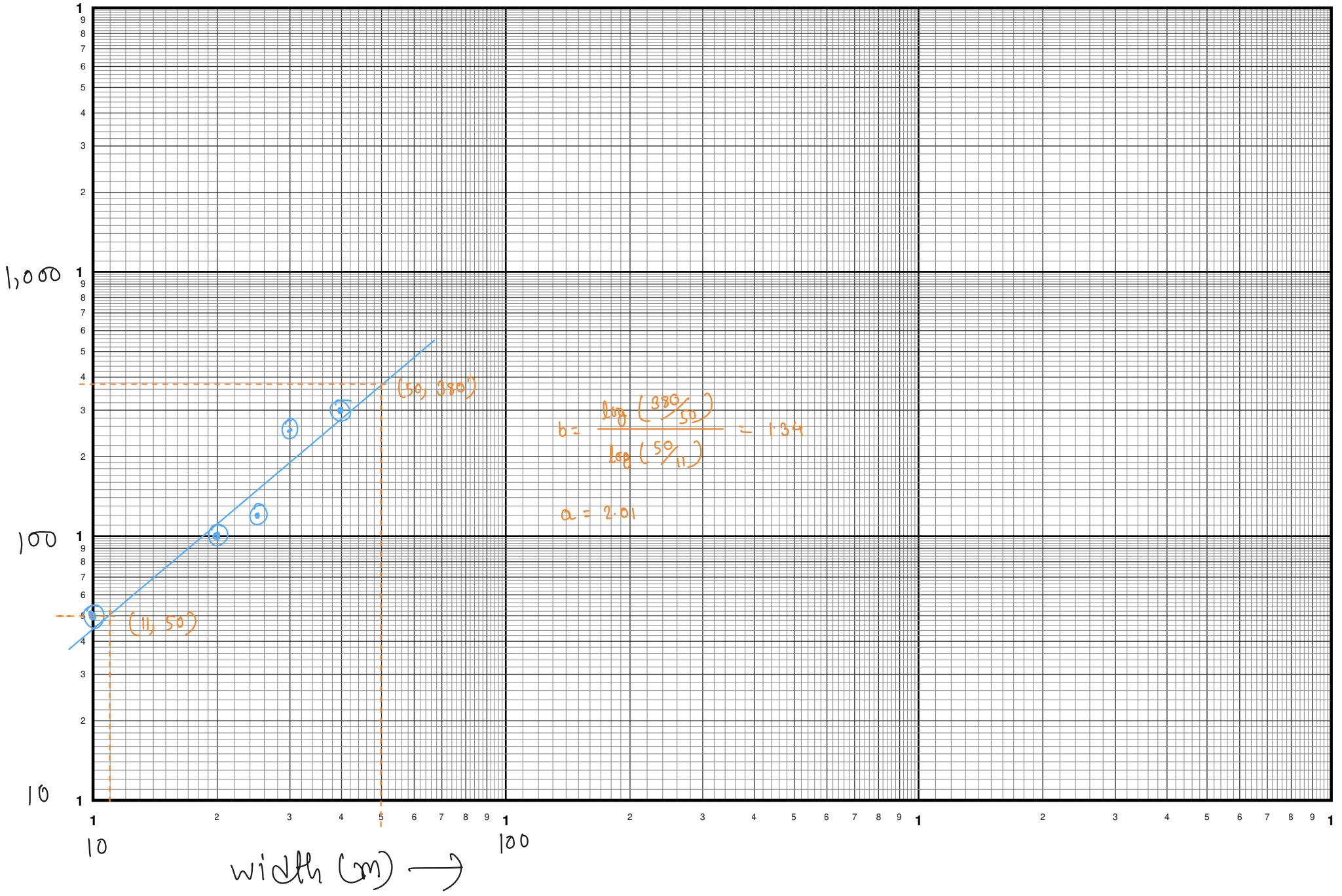
From graph, $\lambda/2 = 2.01 w^{1.34}$

$\Rightarrow \lambda = 4.02 w^{1.34}$

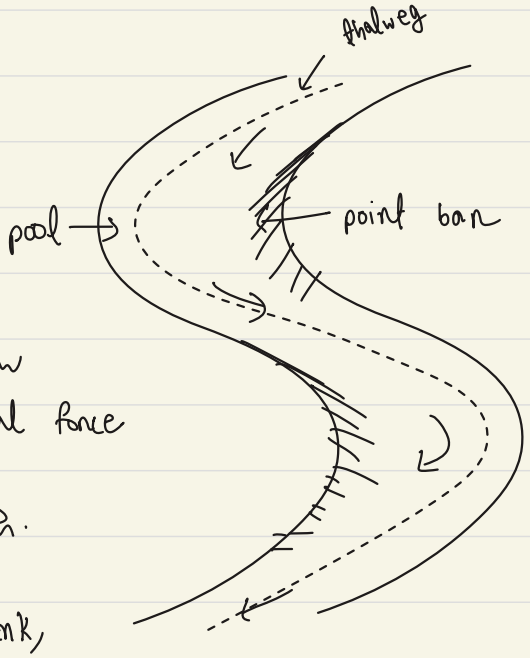
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Secondary flow (helical flow):



As water accelerate around a corner, it develops a centrifugal force, tilting the water upward.

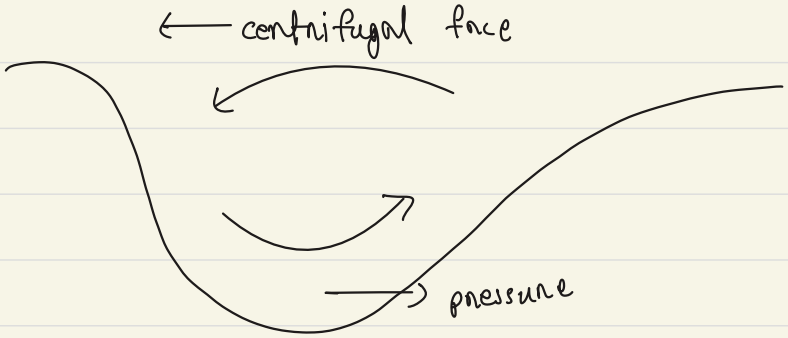
Velocity is high around surface and low around the bottom; so in centrifugal force

Hydrostatic pressure increases w/ depth.

At the surface around the outer bank, centrifugal force dominates and moves current outward.

At the bottom, hydrostatic pressure dominates and moves the current inward (towards point bar)

This causes a secondary current → helical current.



Lec 4

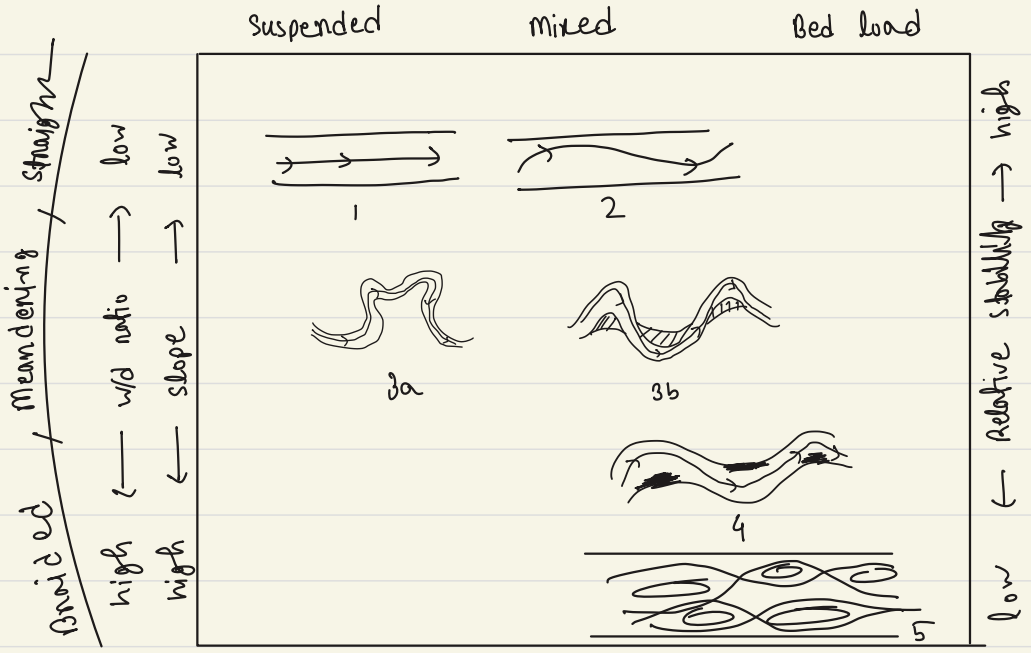
Causes of braiding → 2 theories

1. Two primary cause,
   a. Steep slope
   b. High sediment ld

   → Non-cohesive bed → wide and shallow channel
   when overloaded part of sediment may be deposited
   causing mid-channel bars and multi-channels → braiding.

2. Shallow and deep channel acts as a single unit of deposition/erosion.
   wide and shallow channel cannot do that; part of sediment that can't be carried is deposited creating small numerous channels.

Channel stability:



small	← sediment size →	large
low	← " ld →	high
low	← velocity →	high
low	← stream power →	high

3% > Bed ld / total ld > 11%

Planform Stability ratios: PS ratios

$$PS1 = \frac{\text{Stream eroding power}}{\text{Boundary mat. stren.}} \rightarrow \text{withstand erosive force}$$

$$PS2 = \frac{\text{Bed ld supply}}{\text{Bed ld transport cap.}} \rightarrow \text{transport bed ld}$$

Interpretation: PS1 → At fixed eroding power,
Boundary mat stren ↓ PS1 ↑ Braided

PS2 → At fixed transport cap,
Bed ld supply ↑ PS2 ↑ Braided

Modes of sediment Transport:

sediment ld → sediment particles transported by a flow

- Based on physical nature → particulate ld, dissolved ld
- Presence on bed → bed mats ld, wash ld
- how they travel → bed ld, suspended ld

Bed ld is always bed-mat ld, suspended ld can be bed-mat ld as well as wash ld

→ Bed ld is the sediment ld that travels in contact with or very close to river bed.

Bed mat ld are the ld that are present in the riverbed in non-negligible quantities.

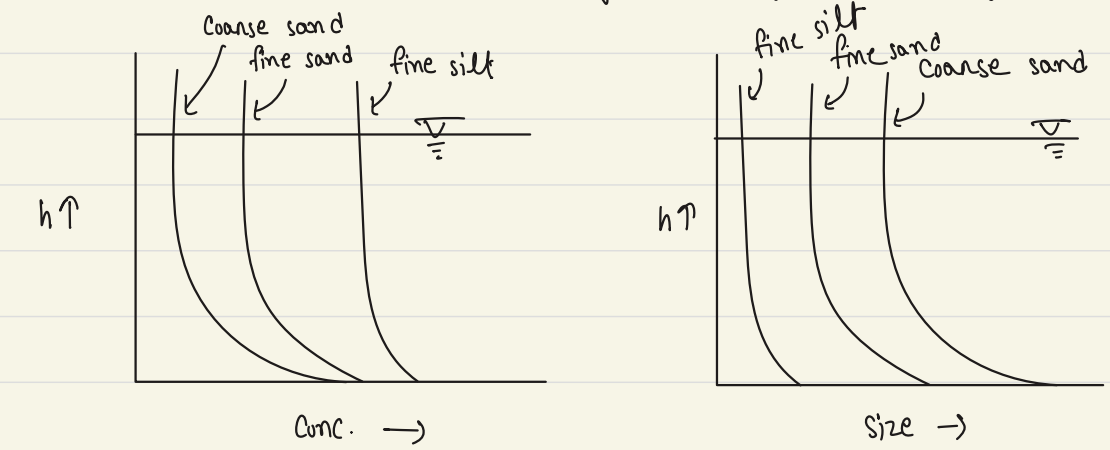
- Because bed ld is in contact with river bed, they are always found in bed.
- when turbulent increases, bed material ld may start to float above riverbed water colum and become suspended ld.

wash ld is always suspended ld.

Distinctions:

1. Dissolved ld: gone into solution
   not important for channel processes (part of flow)
2. Suspended ld: Part of ld that moves through the channel in water column

Size & concentration: varies logarithmically (semi-log; depth in log)



3. wash ld: stays in suspension by thermal molecular agitation. Brownian motion.

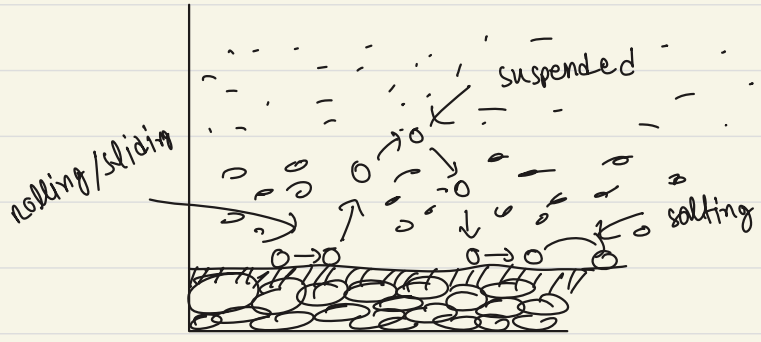
4. Bed ld: capacity limited (than supply)

Classification:

	Based on mode of transport	Presence in bed
Wash ld	Suspended ld	Wash ld
Suspended bed mat ld		Bed mat ld
Bed ld	Bed ld	

No sharp demarcation btwn suspended ld & bed ld:

1. Fluctuating turbulent lift & gravitational settling
2. Size overlap



Wash ld never settles:

1. Negligible mass (0.06 mm – 0.1 mm)
2. Thermal molecular agitation
3. Independence from turbulent
4. Negligible gravity

Bed ld capacity dependent:

1. Unlimited availability from bed
2. Once reaches max ability to transport, no transport

Suspended ld supply dependent:

2. Negligible availability in bed
2. Infinite hydraulic capacity

Lec 5 Forces acting in river

Shear stress:

$$F_g = F_R$$

$$\Rightarrow V\rho \sin\alpha = \tau_0 (2h+w) L \cos\alpha$$

$$\Rightarrow \rho A L g \tan\alpha = \tau_0 P L$$

$$\Rightarrow \tau_0 = \rho \frac{A}{P} g S \quad \Big| \quad A/P = R \rightarrow h, \ \tan\alpha \rightarrow S$$

$$\Rightarrow \tau_0 = \rho g h S$$

Stream power: rate of energy dissipation to bed and bank per unit d/s dist.

$$\Omega = \rho g Q S \quad \Big| \quad \Rightarrow \Omega = \rho g A V S = \rho g w h V S$$

$$\Rightarrow \Omega/w = \rho g h V S = V \tau_0$$

$$v = c\sqrt{hs}$$

$$= c\sqrt{\tau_0/\rho g}$$

$$\Rightarrow v \propto \sqrt{\tau_0} \Rightarrow \tau_0 \propto v^2$$

$$\Omega/w = V \tau_0 \Rightarrow \Omega \propto v^3$$

Strickler's eqn: $n = 0.047 d_{50}^{1/6}$

Sediment movement:

Competence / calibre: Maximum size of particle the flow is capable of carrying.

Capacity: Maximum amount of a given size particle...

Fall velocity: Avg vel a particle would attain if falling freely in water of infinite extent @ 24°C.

Basic mechanism of sediment transport:

1. Gravity for settling
2. Lifting or dragging for suspending and moving d/s

Three forces involved:

1. Gravity force: Opposses the movement

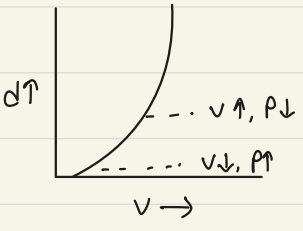
$$F_g = \left(\frac{4}{3}\right)\frac{\pi d^3}{2^3} \times (\rho_s - \rho)g = \frac{1}{6}\pi d^3(\rho_s - \rho)g \rightarrow F_g \sin\alpha$$

2. Drag force: Parallel to river bed. Depends on:

a) Surface roughness
b) Cross-sectional area getting hit } of grains
c) Flow vel.

$$F_d = C_d\left(\frac{\rho u^2}{2}\right)A = C\tau A \rightarrow F_g \cos\alpha \qquad [\tau \propto v^2]$$

3. Lift force: Pressure diff between top & btm of grain causes it to go up.
Negligible after a few grain hits.



Incipient motion:

$$F_D + F_L > F_g$$

↳ ~0

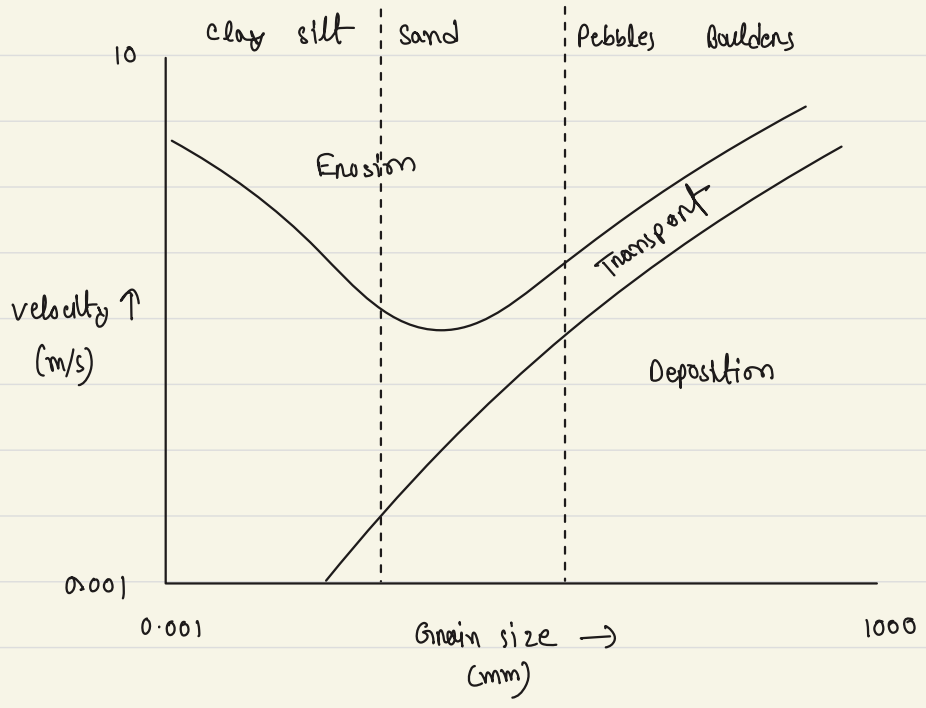
$$\rightarrow \quad C_1 \tau d^2 = C_2 d^3 (\rho_s - \rho) g \qquad [C_2 = 1/6\,\pi\,;\ C_1 = C\,\frac{\pi}{4}]$$

$$\Rightarrow \tau_c = \tau^* d (\rho_s - \rho) g \qquad [\tau^* = \text{critical force} / \text{wt}_{\text{submerged}}]$$

↳ shields param

Shields → τ^* vs $R_e \left(= \frac{ud}{\nu}\right)$

Shield's diagram:



1. Clay requires much higher velocity to be eroded than sands, which requires the least.
2. Once smaller particles are eroded, they never tends to deposit
3. velocity req for erosion and deposition of larger particles are similar → slight decrease, they settle

Shield's param:

hides partly within laminar sublayer

Highest for small particles, lowest for sand, and increases to a const. value for coarse particles.

0.06

$$\tau_c = \tau^* d(\rho_s - \rho)g \rightarrow \tau_c = 0.06\, d\,(2650 - 1000)\,9.81$$

$$\approx 970\, d \qquad [\text{for} > 1\text{cm}\ \ d_{50}]$$

Application:

P21/ $h = 0.3\text{m}$

$s = 0.1/100 = 0.001$

$d = 1\text{mm} = 0.001$

$\tau^* = 0.035$

To erode, $\tau_c = \tau^* d(\rho_s - \rho)g = 0.035 \times 0.001\,(2650 - 1000) \times 9.81 \ \text{N/m}^2$

$= 0.567\ \text{N/m}^2$

Boundary shear, $\tau = \rho g h s = 1000 \times 9.81 \times 0.3 \times 0.001 \ \text{N/m}^2$

$= 2.943\ \text{N/m}^2$

$\tau > \tau_c \rightarrow$ erode

P22/ $w = 55m$

$d = 1\,cm = 0.01\,m$

$S = 0.005$

$C = 32$

Flow to initiate particle motion

$\tau_c = 970d = 9.7\ N/m^2$

$\tau = \rho g h s = \tau_c$

$\Rightarrow 9.7 = 1000 \times 9.81 \times h \times 0.005$

$\Rightarrow h = 0.198\ m$

$v = C\sqrt{hs} = 32\sqrt{0.198 \times 0.005} = 1\ m/s$

$\therefore Q = AV = 1 \times 0.198 \times 55 = 10.89\ m^3/s$

Textural class: MIT → < 0.002 mm → clay

< 0.06 mm → silt

< 2 mm → sand

< 60 mm → gravel

Lec 6 Regimes of Flow

Bed forms: Regular / irregular topography of river bed.
Regimes of flow: Bed forms according to flow conditions.

classification:

1. Ripples
2. Ripples w/ dunes superposed
3. Dunes

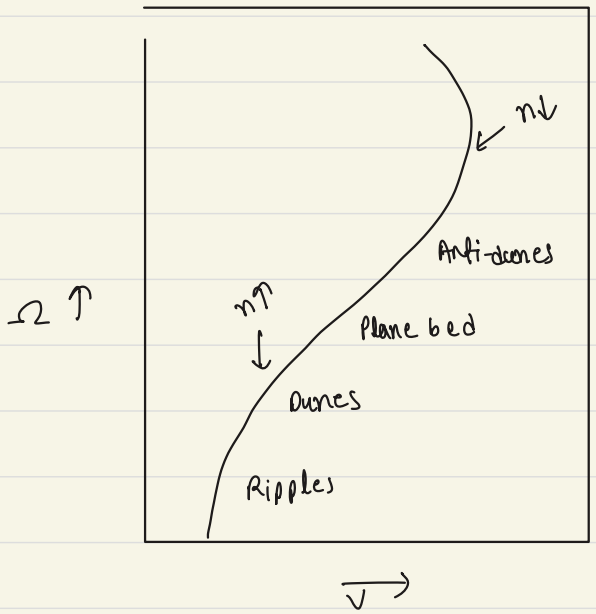
} lower regime

4. Plane bed

} transitional regime

5. Anti-dunes w/ standing waves
6. Anti-dunes w/ breaking waves

} upper regime



$V \propto \frac{1}{n}$

1. Plane bed w/ no sediment movement

$\tau < \tau_c \rightarrow$ no movement

~~$n \rightarrow [0.012, 0.014]$~~

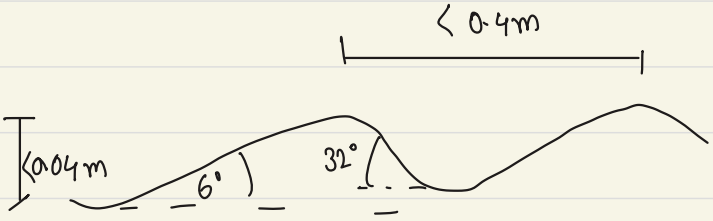
2. Ripples $Fr \ll 1$

$\tau > \tau_c$

~~$n \rightarrow [0.018, 0.030]$~~

~~$10 - 200$ ppm~~

$d_{50} \sim 0.7$ mm



3. Dunes $Fr \ll 1$

$Q \uparrow \rightarrow \Omega \uparrow$

~~$n \rightarrow [0.020, 0.040]$~~

4. Transition $Fr \approx < 1$

~~$n \rightarrow [0.010, 0.013]$~~

5. Anti-dunes $Fr > 1$

~~$n \rightarrow [0.012, 0.020]$~~

~~$5000 - 40,000$ ppm~~

Major diffs btwn upper & lower regimes:

	Lower regime	Upper regime
Forms	Plane, ripples, dunes	Plane, anti-dunes
n	greater → 0.016 - 0.026	0.013 - 0.022
Sediment	lower → 0 – 800 ppm	1000 – 42,000 ppm
Fr	$<< 1$	≈ 1 – $>> 1$

Resistance to flow:

Before sediment movement ($\tau < \tau_c$) → normal formula
After → complicated

Roughness = grain roughness + form roughness
K_s K_{s1} K_{s2}

when which dominates:

- In most practical scenarios, form roughness dominates
- Form roughness (K_{s2}): (Lower flow regime)
  when assymetrical bed form exists, the pressure difference over the bed causes drag effect against flow direction, exceeding skin friction.
- Grain roughness (K_{s1}):
  on gravel-bed rivers
  when bed is plane ($K_{s2} \approx 0$)

Why roughness coeff. change from lower to upper flow regime.

- Roughness = grain + form roughness
- on lower regime: assymetrical ripples & dunes cause flow seperation and eddies making form resistance dominant (0.018-0.040)
- on upper regime: high stream power washes away bedforms and form resistance vanishes virtually. (0.010-0.022)

Impact of eddies:

1. Sediment transport → lifts & transports
2. Channel roughness

Fall velocity of particles:

Sphericity → A_s/A_p ; A_p → test particle; A_s → sphere of same vol

Shape factor → $C/\sqrt{ab}$; C → minor axis; a, b → major, intermediate axis

Deposition depends on → submerged wt
viscous resistance, inertia eff

$$N_{Re} = \frac{wD}{\nu} \qquad \left[\nu = \frac{\mu}{\rho}\right]$$

$N_{Re} < 1$ → viscous

$$w = \frac{1}{18} \frac{d^2}{\mu} (\rho_s - \rho) g$$

$N_{Re} > 1000$ → inertial

$$w = \sqrt{\frac{4}{3} \frac{gd}{C_D} \left(\frac{\rho_s - \rho}{\rho}\right)}$$

$$C_D = \frac{24}{N_{Re}} + \frac{3}{\sqrt{N_{Re}}} + 0.34$$

N_{Re}	C_D	w
< 1	$24/N_{Re}$	$\frac{1}{18}\frac{gd^2}{\mu}(\rho_s - \rho)$
$1 - 1000$	$\frac{24}{N_{Re}} + \frac{3}{\sqrt{N_{Re}}} + 0.34$	$\sqrt{\frac{4}{3}\frac{gd}{\phi C_D}\left(\frac{\rho_s - \rho}{\rho}\right)}$
> 1000	0.44	$\sqrt{\frac{4}{3}\frac{gd}{\phi C_D}\left(\frac{\rho_s - \rho}{\rho}\right)}$

P36/ $d = 1mm = 0.001\ m$

$\phi = 0.90$

$G_s = 2.1$

$\nu = 1.003 \times 10^{-6}\ m^2/s$

Assuming laminar flow:

$$w = \frac{1}{18}\frac{gd^2}{\mu}(\rho_s - \rho)$$

$$= \frac{1}{18}\frac{9.81 \times 0.001^2}{1.003 \times 10^{-3}}(2100 - 1000) \quad [\mu = \nu \times \rho = 1.003 \times 10^{-6} \times 10^3 = 1.003 \times 10^{-3}]$$

$$= 0.598 \quad m/s$$

$$N_{Re} = \phi\frac{wD}{\nu} = 0.9\frac{0.598 \times 0.001}{1.003 \times 10^{-6}} = 536 > 1$$

Therefore turbulent:

$$C_D = \frac{24}{N_{Re}} + \frac{3}{\sqrt{N_{Re}}} + 0.34 = 0.514$$

$$w = \sqrt{\frac{4}{3}\frac{gd}{\phi C_D}\frac{(\rho_s - \rho)}{\rho}} = 0.176\ m/s$$

w_0	N_{Re}	C_D	w_1	Diff
0.598	537	0.514	0.176	
0.176	158	0.731	0.148	
0.148	133	0.781	0.143	
0.143	128	0.792	0.142	

$\therefore w = 0.142\ m/s$

Re: P86/ $d = 1\,mm = 0.001\,m$

$\phi = 0.90$

$\rho_s = 2.1$

$\nu = 1.003 \times 10^{-6}$

Assume laminar:

$$w = \frac{1}{18}\frac{gd^2}{\rho\nu}(\rho_s - \rho) = \frac{1}{18}\frac{9.81 \times 0.001^2}{1.003 \times 10^{-3} \times 1000}(2100 - 1000)$$

$$= 0.598\ m/s$$

$$N_{Re} = \phi\frac{wD}{\nu} = 0.9\frac{0.598 \times 0.001}{1.003 \times 10^{-6}} = 537 > 1$$

∴ Turbulent:

$$C_D = \frac{24}{N_{Re}} + \frac{3}{\sqrt{N_{Re}}} + 0.34 = 0.514$$

$$w = \sqrt{\frac{4}{3}\frac{gd}{\phi C_D}\frac{\rho_s - \rho}{\rho}} = \sqrt{\frac{4}{3} \times \frac{9.81 \times 0.001}{0.9 \times C_D} \times 1.1} = \frac{0.1264}{\sqrt{C_D}} = 0.176$$

w_0	N_{Re}	C_D	w_1	$w_0 - w_1$
0.598	537	0.514	0.176	0.422
0.176	158	0.731	0.148	0.028
0.148	132.8	0.781	0.143	0.005

Lec 7 Estimation of sediment transport rate

$\tau = \rho g h s$
$\tau_c = \tau^* g d (\rho_s - \rho)$
} $\tau > \tau^* \rightarrow$ particle $\rightarrow$ bed moves

$\tau/\rho = ghs \rightarrow \frac{L}{T^2} L \frac{L}{L}$

$= \frac{L^2}{T^2}$

$\Rightarrow \sqrt{\frac{\tau}{\rho}} \rightarrow \frac{L}{T}$ (velocity)

$\Rightarrow u^* = \sqrt{\tau/\rho} \rightarrow$ shear vel.

ω : fall vel.

deposit ← fall

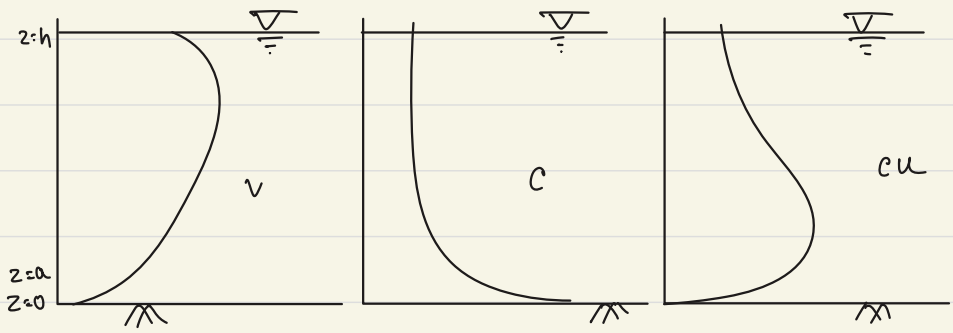
$\frac{\omega}{u^*} \rightarrow$ whether particle stays in motion or falls

suspention ← motion

Sediment ld → product of vel & conc.

$q_s = \int c u \, dy$

Complex to int.



Approx. suspended sediment conc.:

$$\frac{C}{C_a} = \left[\frac{D-y}{y} \times \frac{a}{D-a}\right]^{R_n} ; \quad R_n = \frac{w}{K u^*} ; \quad K = 0.4$$

small value

→ upper → [small x small]^{R_n} → low conc.

→ lower → [less small x small]^{R_n} → ↑ surface conc.

Limitations: At $y = D$, $C \to 0$; not true

Rouse Number:

$$R_n = \frac{w}{K u^*} ; \quad K = 0.4$$

R_n: > 2.5 → bed ld

$(1.8, 2.5)$ → transition

< 1.8 → full suspension

≤ 0.25 → wash ld

P11/ $D = 4m$

$S = 2.25 \times 10^{-4}$

$d_{50} = 0.4\,mm = 0.0004\,m$

$w = 0.04\,m/s$

$a = 0.4m$; $C_a = 400\,ppm$

$y = 1\,m$

$$\frac{C}{C_a} = \left[\frac{D-y}{y}\ \frac{a}{D-a}\right]^{R_n}$$

$$\Rightarrow C = 400\left[\frac{4-1}{1} \times \frac{0.4}{4-0.4}\right]^{1.064}$$

$$\therefore 124\ ppm\ (= mg/L)$$

$$R_n = \frac{w}{K u^*}; \quad = \frac{0.04}{0.4 \times 0.0940} = 1.064$$

$$u^* = \sqrt{ghs} = \sqrt{9.81 \times 4 \times 2.25 \times 10^{-4}} = 0.0940$$

To become bed ld, $R_n = 2.5$

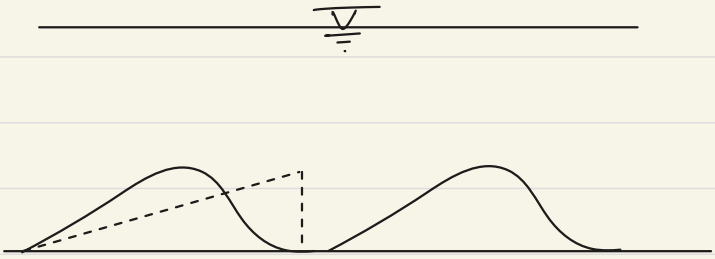
$$= \frac{w}{0.4 \times 0.094} = 2.5$$

$$\Rightarrow w = 0.094\ m/s$$

Suspended ld transport rate:

$$Q_s = C_{av} Q; \qquad C_{av} \approx A^{1/2} S^{2/3}$$

Bed ld:



$q_b \rightarrow$ kg/yr

$q_b = v\, m_s$ ← migration vel

$v = 10\%\ v_{mean}$

$m_s = \frac{1}{2} L\, DH \times \rho_s (1-P)$ ← porosity

α ↙ 0.5 ~ 0.7

ρ_s ← 2650 kg/m3

P14/ $w = 160\ m$

$n = 0.023$

$h = 2.2\ m$

$S = 0.08\% = 0.0008$

$L = 80\ cm = 0.8\ m$; $DH = 15\ cm = 0.15\ m$

$P = 50\%$

$v = 30\%$ of v_{mean}

$$v_{mean} = \frac{1}{n} R^{2/3} \sqrt{S} = 2.08\ m/s \qquad [R = h = 2.2\ m]$$

$$\therefore q_b = (0.3 \times 2.08) \times \left(\frac{1}{2} \times 0.8 \times 0.15 \times 2650 (1-0.50)\right)$$

$$= 0.624 \times 79.5 = 49.61\ kg\text{-}m/sec$$

$$\therefore Q_b = 49.61 \times 160 = 7938\ kg/sec$$

Meyer-Peter & muller eqn:

$$q_b = 0.253 (\tau_0 - \tau_{cr})^{3/2}$$

P15/ $h = 2.5\,m$ $\quad w = 50\,m$

$S = 0.0015$

$d_{50} = 3.2\,cm = 0.032\,m$

$\tau = \rho g h S = 1000 \times 9.81 \times 2.5 \times 0.0015 = 36.79\ Pa$

$\tau_{cr} = 970\,d = 970 \times 0.032 = 31.04\ Pa \quad < \tau$

$\therefore q_b = 0.253 (36.79 - 31.04)^{3/2} = 3.49\ kg.m/s$

$\therefore Q_b = 50 \times 3.49 = \cdots\ kg/s$

Criteria for sediment transport:

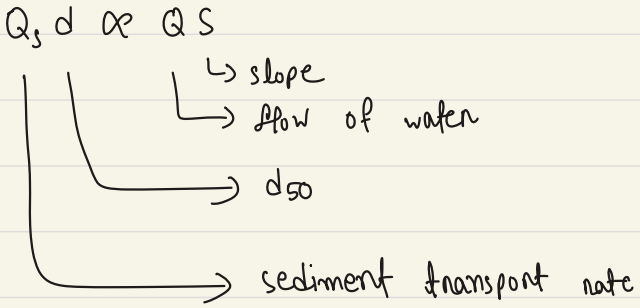
Bed ld $\rightarrow$ $\tau > \tau_c$

suspended ld $\rightarrow$ $Ku^* > w$

wash ld $\rightarrow$ $D_{50} < 0.063\ mm$

Lec 8 Dynamic Adjustment of River System — Lane's Rltnshp

Qualitative relation:



$$Q_s \propto \frac{QS}{d}$$

sediment ld, $C_s = \frac{Q_s}{Q_w} \rightarrow C_s = f(S, 1/d)$

Limitations:

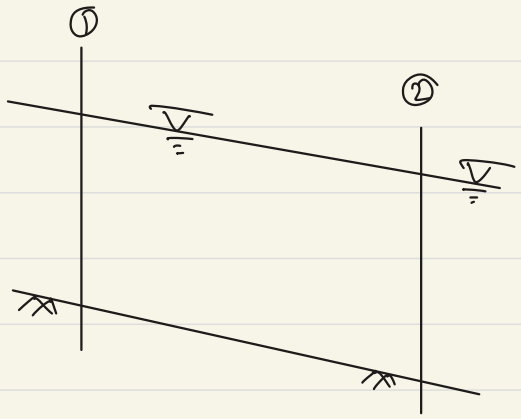
1. Qualitative; no quantitative estimate of change
2. No temporal component → how long to take effect
3. Doesn't address cross-section or planform change

$Q_s d \propto Q S$ deposition u/s

$Q_s d \propto Q_w S$ erosion u/s

$Q_s d \propto Q S$ erosion u/s

$Q_s d \propto Q S$ deposition u/s



Quantitative analysis:

$$Q_s d \propto Q_w S$$

$$a\left(b/c\right)^{Y_3} = de \quad ; \quad a = \frac{Q_{s2}}{Q_{s1}} \; ; \; b = \frac{d_{50,2}}{d_{50,1}} \; ; \; c = Y_2/Y_1$$

$$d = \frac{Q_{w,2}}{Q_{w,1}} \; ; \; e = S_2/S_1$$

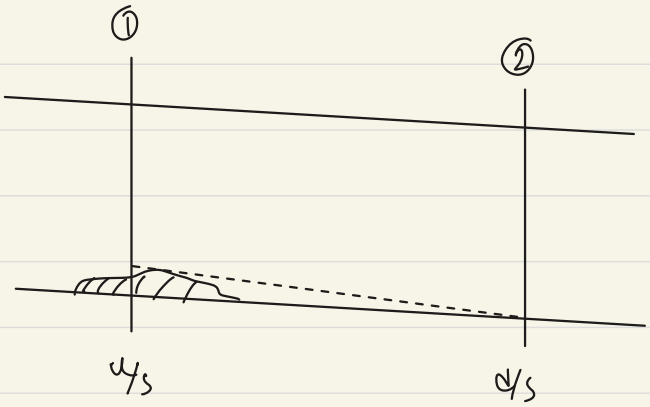
P09/ $d = 0.9$; $Q_{w2} < Q_{w1}$

$a = 0.99$; $Q_{s2} \approx Q_{s1}$

$b = 1$; $d_2 = d_1$

$c = 0.95$; $Y_2 < Y_1$

water discharge has reduced but sediment discharge has not. The channel must deposit excess sediment u/s.



slope increase

$$a\left(\frac{b}{c}\right)^{1/3} = de$$

$$\Rightarrow 0.99 \times \left(\frac{1}{0.95}\right)^{1/3} = 0.9\,e$$

$$\Rightarrow e = 1.12$$

∴ 12% incn. in slope w.r. to d/s

Aggradation & degradation:

Aggradation → increase in bed level of a river.
Degradation → decrease in " " of a " .

Diff: 1. A related to bed lvl rising
1. D " " " " lowering

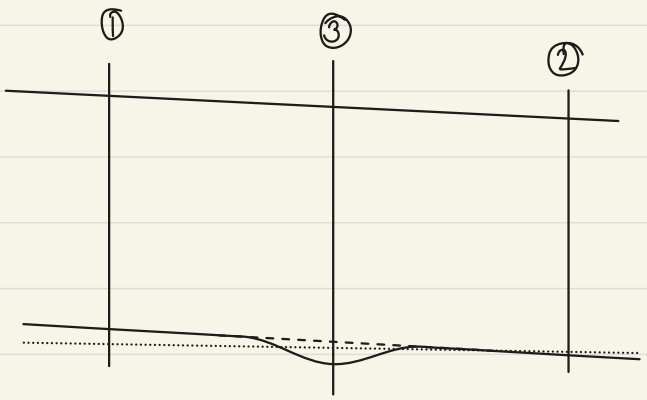
2. A happens on sediment loaded rivers
2. D " " " deficit "

3. A related to deposition
3. D " " erosion

4. A when river lacks stream power
4. D " " picks-up " "

Similarity: Both happen over a long period.

Dredging:



S ↑ w.r. to u/s → Ω ↑ → degradation u/s
S ↓ w.r. to d/s → Ω ↓ → aggradation at ③ & d/s

u/s of dam → aggradation

$D \uparrow \rightarrow v \downarrow \rightarrow \Omega \downarrow \rightarrow$ deposit

d/s of dam → degradation

$Q_s \downarrow$ → erosion

Release of clear water → aggradation at u/s
degradation at clear water path

water supply diversion → aggradation just d/s

Flood discharge increase → degradation during peak stage
aggradation in receding

Tributary confluence → degradation if proportionally less sediment
aggradation if large sediment ld arrives

Distributary take off → Aggradation just d/s of off-take

2024/8/d

$a = 1.3$

$b = 1.0$

$c = 1.05$

$d = 1.1$

$e = ?$

$a(b/c)^{1/3} = de$

$\Rightarrow e = 1.16$

Sediment ld increased by 30%
but discharge did not increase that much
therefore, stream power lacks the
ability to transport

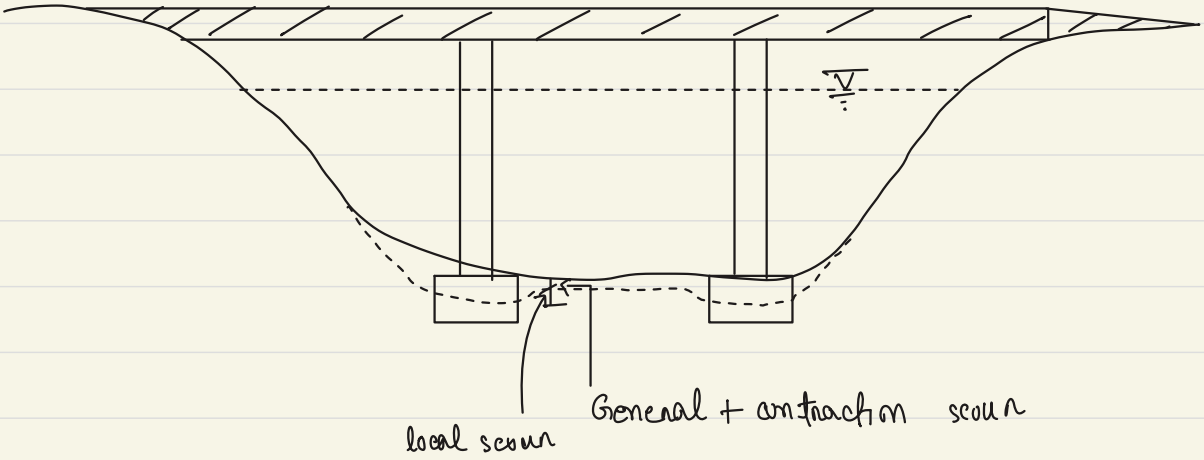
Excess sediment is deposited u/s, increasing slope by 16%
w.r. to d/s.

Lec 9 River scouring

River scour is the result of erosive action by flowing water

Total scour: General scour, Localized scour

- General scour
  - aggradation
  - degradation
- Localized scour
  - contraction scour
  - local scour



General scour: Long-term streambed scouring that'd happen regardless of placement of obsticles or constriction.

Contraction scour: Due to flow width reduction by placement of obstacles / structures

Local scour: around pier or structure due to acceleration of flow, localized vortices, etc.

Diff: Contraction scour is diff than long term because it happens in the vicinity of constriction or bridge; not longitudinally.

Scour at bridge pier & abutment:

Due to formation of vortices around the pier:

1. Horseshoe vortex: pile up of water around the u/s surface of pier, goes around the pier with increased acceleration. This removes bed material from around the base of pier.

   As depth increases, their stren is reduced & equil. reached

2. Wake vortex: vertical vortices d/s of pier.
   Intensity decreases rapidly as distance d/s of pier incr.

Diff: horseshoe vs wake vortex:

H: Forms at the u/s side of pier
W: " behind the pier (d/s)

H: Goes around the the pier, sideways
W: Goes vertically downward

Factors affecting scour depth:

(i) velocity
(ii) Flow depth & pier width
(iii) Bed materials
(iv) Shape of pier
(v) Angle of attack

Relⁿ w/ velocity:

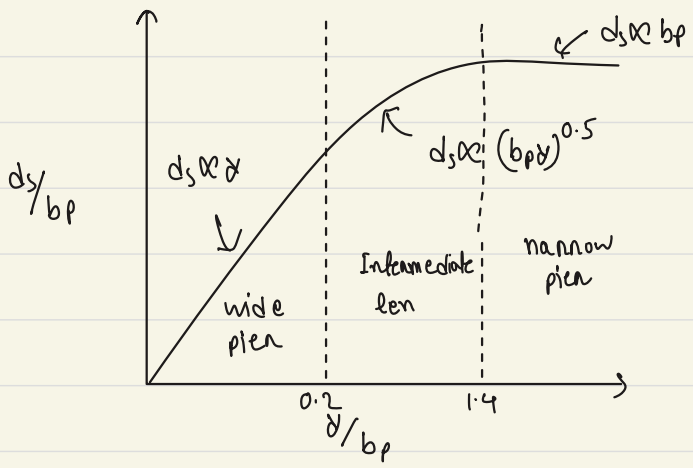
$D_s \propto (V/V_c)^n \; D(y)$



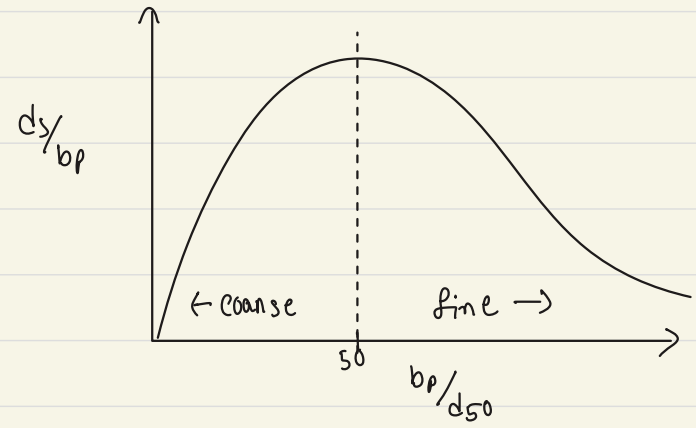
Effect of flow depth & pier width :

$y/b_p \leq 0.2 \rightarrow$ wide pier $\rightarrow$ y controls

$y/b_p \geq 1.4 \rightarrow$ narrow pier $\rightarrow$ b controls



Sediment coarseness :



Pier shape: (K_1)

Square → 1.1

Circular / round / group → 1.0

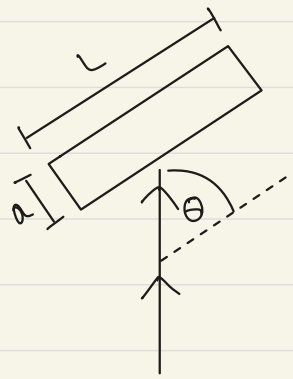
Sharp → 0.9

For angle of attack < 5°

else $K_1 = 1$; K_2 dominates

Angle of attack:

Angle between flow dir & pier's long axis.



$$K_2 = \left(\cos\theta + L/a \sin\theta\right)^{0.65} \leq 5.0$$

Abutment scour: (K_s)

Occurs when abutment obstructs the flow

Around the base and toe

Horseshoe vortex + wake vortex

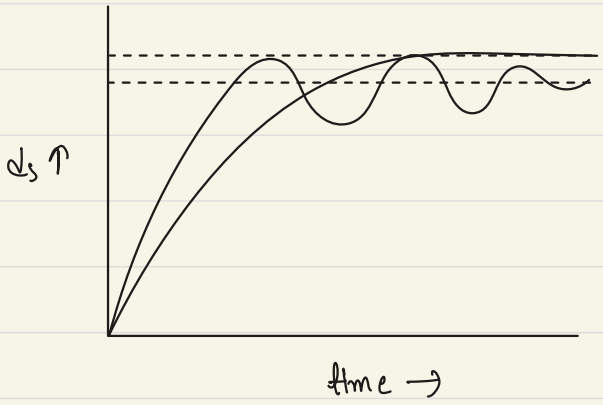
Clean water & live bed scour:

At the u/s of pier: $V_{mean} < V_c \rightarrow$ clean water scour

$V_{mean} > V_c \rightarrow$ live bed scour

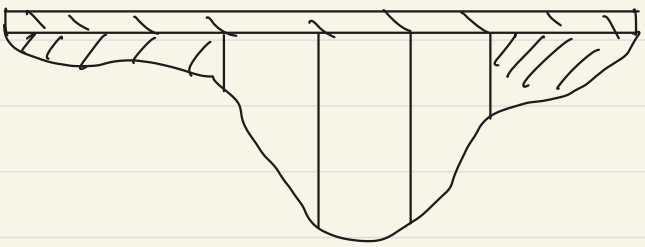
Scour depth is higher for clean water scour:

1. flow is sediment starving
2. eroded area does not get deposited by u/s sediment
3. Stream power is not reduced by ripples, dunes, or water particles.



Contraction scour not significant:

For two cases contraction: Floodplain/bank fillup
Piers width reducing flow area



Discharge around bank is insignificant and doesn't cause much vel increase if routed through main channel

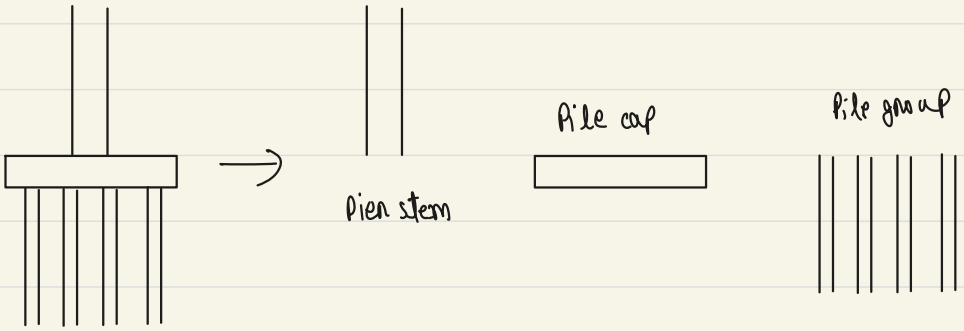
Lec 10 River scour (cont.)

Normal pier → pier cap, pier/column
Complex pier → column, pile cap, pile group

why always complex pier pref:

1. Increased ld cap
   single col may buckle
   Provides both vert. & hor. protection
2. Reach deep stable soil strata
3. Protection from ship collision (pile cap)
4. seismic protection

Scour components:



$$y_s = y_{s,ps} + y_{s,pc} + y_{s,pg}$$

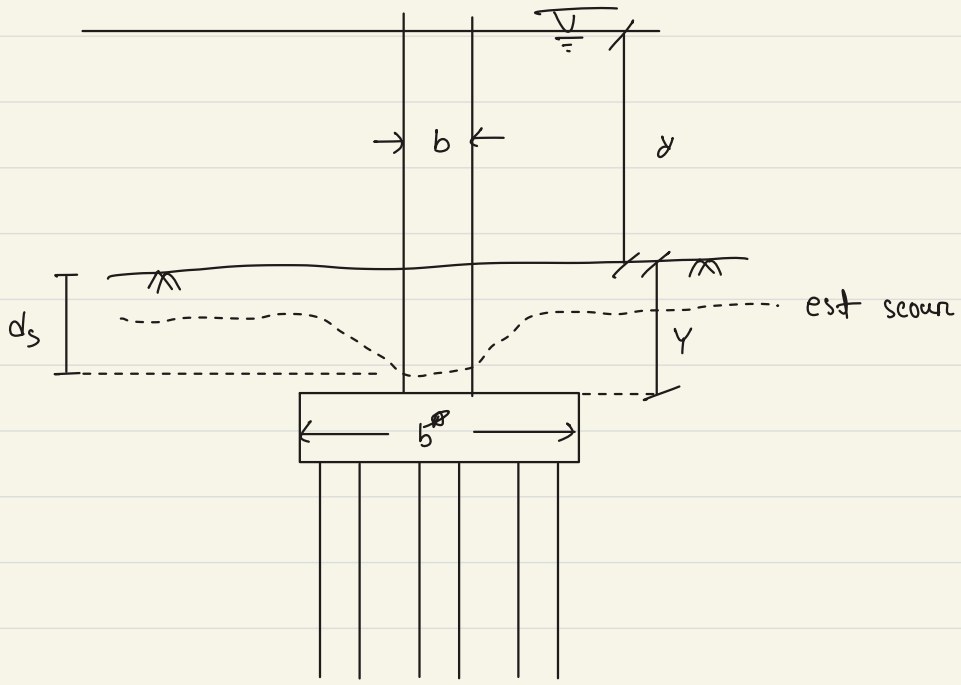
Four cases:

(i) Pile cap is below est. scour depth
→ normal pier

(ii) Pile cap is at est. scour depth, exposed
→ normal pier; better preventing scour

(iii) Pile cap is above river bed but below water surface
→ Complex pier.

(iv) Pile cap is at or above water surface
→ complex pier



Effective pier diameter:

$$b_e = b\left(\frac{d+Y}{d+b^*}\right) + b^*\left(\frac{b^*-Y}{b^*+d}\right)$$

$b \rightarrow$ Col width / dia $\qquad b^* =$ pier width

$d \rightarrow$ flow depth

$Y \rightarrow$ dist betwn river bed and top of pile cap

Est. of scour depth:

$$\frac{d_s}{Y_1} = 2.0\, K_1 K_2 K_3 K_4 \left(\frac{a}{Y_1}\right)^{0.65} Fr_1^{0.43}$$

$K \rightarrow$ nose, angle, bed mat, armoring factor

P24/ Normal pier

$b = 1.5\ m = a \qquad d = 3\ m$

$V = 2.0\ m/s \qquad K_1 = 1;\ K_2 = 1;\ K_3 = 1.1;\ K_4 = 1$

$$\frac{d_s}{d} = 2.0 \times K_1 K_2 K_3 K_4 \left(\frac{b}{d}\right)^{0.65} Fr_1^{0.43}; \qquad Fr_1 = \frac{V}{\sqrt{gd}} = 0.37$$

$\Rightarrow d_s = 0.91 \times 3 = 2.74\ m$

P25/ $b = 1.5\,m$

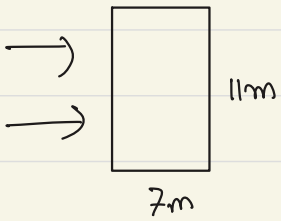
$d = 3.0\,m$

$Y = 2.0\,m$

$K_1 = K_2 = K_4 = 1$

$K_3 = 1.1$

$a = 7\,m$



$$\frac{d_s}{d} = 2.0\,K_1 K_2 K_3 K_4 \left(\frac{b_e}{d}\right)^{0.65} Fr_1^{0.43}$$; $Fr_1 = 0.37$

$$\Rightarrow d_s = 6.27\,m$$

$$b_e = b\left(\frac{d+Y}{d+b^*}\right) + b^*\left(\frac{b^*-Y}{b^*+d}\right)$$

$$= 1.5\left(\frac{3+0}{3+7}\right) + 7\left(\frac{7-0}{7+3}\right)\ m$$

$$= 5.35\,m$$

Recap :

$$b_e = b\left(\frac{d+Y}{d+b^*}\right) + b^*\left(\frac{b^*-Y}{b^*+d}\right)$$;

$b \rightarrow$ pile col width

$d \rightarrow$ flow depth

$Y \rightarrow$ bed to cap top

$b^* \rightarrow$ pile cap width

$$d_s/d = 2.0 \times K_1 K_2 K_3 K_4 \left(\frac{b}{d}\right)^{0.65} Fr_1^{0.43}$$

Lacey – Inglish method:

$$D_{se} = 2.0\, D_{LQ} \;; \quad D_{LQ} = 0.47\left(\frac{Q}{f}\right)^{1/3} \;; \quad f = 1.76\sqrt{d_{50}}$$

(Q: m^3/s; D_{LQ}: m; d_{50}: mm)

P27/ $Q = 380\ m^3/s$

$d = 4.11\ m$

$d_{50} = 0.17\ mm$

$b^* = 4.2\ m$

$Y = 0$

$b = 1\ m$

$$b_e = b\left(\frac{d+Y}{d+b^*}\right) + b^*\left(\frac{b^*-Y}{b^*+d}\right)$$

$$= 1\left(\frac{4.11+0}{4.11+4.2}\right) + 4.2\left(\frac{4.2-0}{4.2+4.11}\right) = 2.62\ m$$

$$D_{LQ} = 0.47\,(Q/f)^{1/3} \;; \qquad f = 1.76\sqrt{d_{50}}$$

$$= 0.47 \times \left(\frac{380}{0.73}\right)^{1/3}\ m \qquad = 1.76\sqrt{0.17} = 0.73$$

$$= 3.78\ m$$

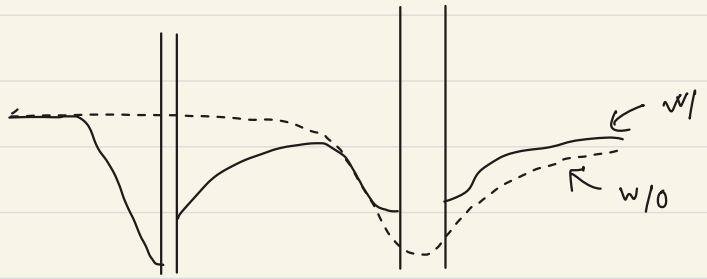
$$\therefore D_{SE} = 2 \times 3.78 = 7.56\ m$$

Bridge pier scour protection:

1. Armoring countermeasure → withstand the erosive force of flow by acting as a resistant layer and protect bed underneath.
   E.g., rip-rap, gabion
2. Flow altering counter-measure → deflects incoming flow or reduce stream power.
   E.g, collar, sacrificial piles.

Collar: devices attached to pier at some level closer to bed
They absorbs the horseshoe vortices and downward flow.
Protective disk made of steel or concrete.

Sacrificial piles: Piles of small diameted placed u/s of bridge piers. They suppress the approaching flow, creating a wake region d/s, and deflect high velcity flow



Why not in BD: extreme scour depth (60m+)
navigation issue
cost

Lec 11 River training

River training structures:

1. Transverse struct. → perpendicular to flow
   active
   redirect, reduce bank & bed scouring
   Spurs / groynes, sills, Bandals, Porcupines

2. Longitudinal struct → along the river bank
   passive
   prevents erosion
   rip-rap, guide banks, embankments, revetments

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1. Hardcore bank prot → man-made rigid struct
2. Soft core → NBS; utilizing natural materials and vegetation

Spurs: Structure built across the flow from a bank into the river

↙ or groyne

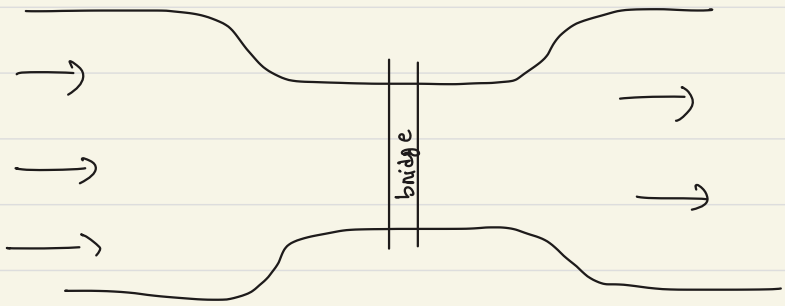
Functions: i) train the river to a desired course
ii) create a slack zone (zone of reduced flow) for natural bank formation.
iii) Protect bank by keeping flow away

Classification: based on permeability, submergence, orientation, head

Permeability: Permeable, impermeable
Submergence: submerged, non-submerged
Orientation: Attracting (∠), deflecting (⊥), repelling (>)
Head: T, L, I, O, ...

Guide bank:

Longitudinal river training structure to narrow its course axially.



They are provided on both banks unless one side has non-erodible bank.

Launching apron: Flexible stone covers placed on bed which settles into scouring area as scouring takes place.

Porcupines:

Permeable struct, both longitudinal & transverse, designed to reduce flow on trap sediment.

Two types → tetrahedal → six concrete struts
prismatic → nine " "

Revetment:

Continuous artificial protective facing placed along the riverbed to absorb incoming water energy and protect bank.

Two types: Close joint → gaps btwn individual hard surface are closed via cement or stuffs.
Possess detrimental head; only used when wtr lvl doesn't fluctuate or not of concern.

Open joint → gaps remain open allowing free water flow.

Structural comp. → cover layer, filter layer, toe protection

Riprap → Protective facing consisting of roughly angular rocks used to armor embankments.

Gabions → wired box consisting of small stones.

Riprap → armor layer, filter layer, toe protection layer.

Riprap vs gabions → i) R → 30 cm dia rocks
G → 8–20 cm

ii) R → slope 1:2
G → much steeper as they are in wire mesh

iii) R → costly
G → cheap

Nature-based solutions:

Natural processes and materials to reduce water flow, erosion, and enhance ecological health — an alternative to traditional infra.

→ Use of vegetation & natural materials for bank prot.
→ Cost eff. in terms of materials, labor.
→ maintenance free once set.
→ Req time to establish

Adv.: Cost eff
carbon benefits
social inclusiveness
self sustaining / Regenerative

Disadv.: No immediate prot
Low hydraulic prot
High initial vulnerabilities
Uncertainty

Bandals: Traditional low-cost bamboo river structures positioned at an angle to the flowing water.

Purpose: Navigation → diverts upper layer flow towards thalweg
dry session
Bank protection

Lec 12: Navigation

Navigable water: bodies of water that can be used for commerce and transportation (of goods and/or people)
→ deep, wide, calm enough for water vessel to pass safely.

Adv. → least cost (1:2:5) → river: rail: rd
least energy (1:1.5:4)
land saving
env. friendly
decongestion
safety
+ no maintenance of rd

Disad. → time

Two factors affecting nav:

1. channel dim (morphological → depth, width, curvature)
2. flow cond. (flow factors → vel, pattern of flow)

Morphological /



Depth: > draft
more depth → less energy (less drag)

Channel width: two way traffic

Channel rad. of curve → 3 times of tow-barge fleet

Cross-sectional area → Blockage factor: A_c/A_v; A_c → channel
A_v → vessel (submerged)

BF ≥ 6 for two way x-section

Flow factors /

velocity → < 3 m/s (longitudinal)
Transverse/ helical current → < 0.3 m/s

Hazardous flow pattern → 3

Shoals → not enough depth
rapid → currents too strong
hazard → dangerous → vortices