WRE — 311

Dr. Ehtesham sir
732 room no

22/02/2020
Lec—01

Open Channel flow

Reference: 1. Open channel hydraulics by Ven Te Chow (main)

2. Open channel ~~flow~~ hydraulics by Richard H. French

3. Flow through open channels by K.G. Ranga Raju.

4. Abdul halim sir এর lecture note. (Lecture note on open channel flow).

Hanif Chowdhury → open channel flow

Subramanya → problems নেয়া যাবে

CT schedule:

1. 1st CT — 3rd week এ [1:15 এ]
2. 2nd CT — 9th week এ

Content:

- Open channel flow and its classification.
- Uniform flow ~ varied.
- Gradually ~~direct~~ flow, calc. of gradually varied flow.
- Principles of flow measurement and devices.

Open channel flow → gravity এর জন্য হয়, atm pressure

Pipe flow → pressure difference এর জন্য flow হয়। atm pressure থাকে না।

Sir uniform flow পড়াবেন। অন্য part এ critical flow.

Time duration বেশি হলে rapidly varied flow হয়, not gradually varied flow.

Lec-02
24/02/2020

Types of open channel flow:

(a) Steady and ~~unstre~~ unsteady flow:

$\frac{\partial h}{\partial t} = \frac{\partial v}{\partial t} = \frac{\partial Q}{\partial t} = 0$ [কোন particular location এ depth of water level, velocity, discharge w.r.t. ~~time~~ time unchanged]

(b) Uniform and varied / non uniform flow:

$$\frac{\partial h}{\partial x} = \frac{\partial v}{\partial x} = \frac{\partial Q}{\partial x} = 0$$ [space এর respect এ কোন নির্দিষ্ট time এ h, Q, v change হয় না]

Varied flow —

i) Gradually varied flow

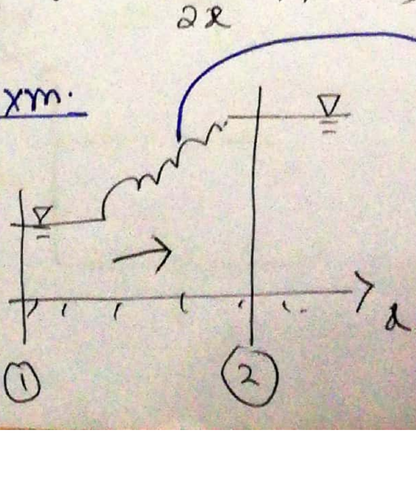
$$\frac{\partial h}{\partial x} \approx \frac{\partial v}{\partial x} \approx 0$$ [variation টা যদি small হয়]

এটা আবার steady বা unsteady হতে পারে

ii) Rapidly varied flow –

change in the h, v, অনেক short distance এ rapidly change হয় $\frac{\partial h}{\partial x} >> 0$; $\frac{\partial v}{\partial x} >> 0$ [diff. location এ]

Exm.



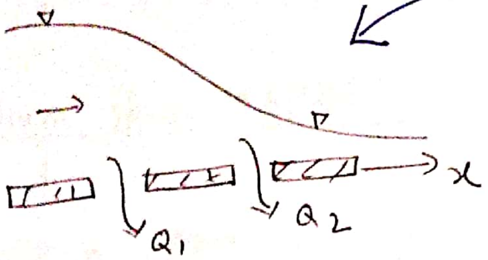
hydraulic jump (if the flow changes from supercritical to subcritical) অনেক কম distance এই change ... (artificial channel এ)

iii) **Spatially varied flow:**

Along the Length of the channel, discharge যদি vary করে।

$$\frac{\partial Q}{\partial x} \neq 0$$

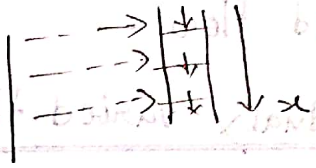
Exm:

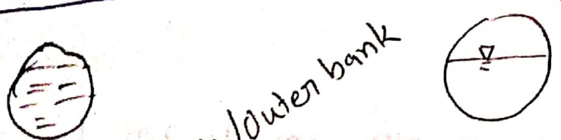


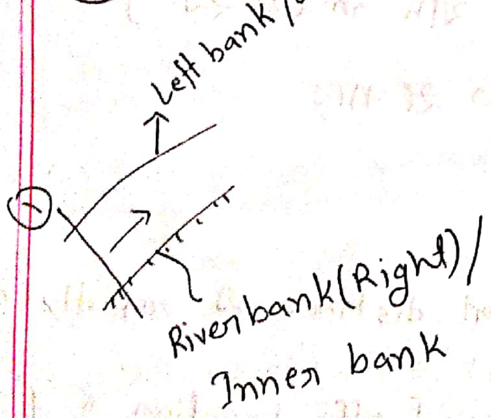
Flow over a bottom rack
↓
steady spatially varied flow

unsteady
↓
flow through roadside gutter

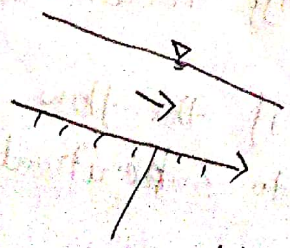
(rainfall non-uniform হয়)



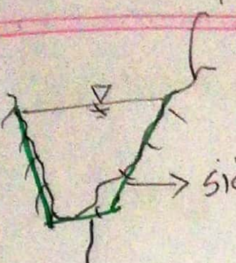




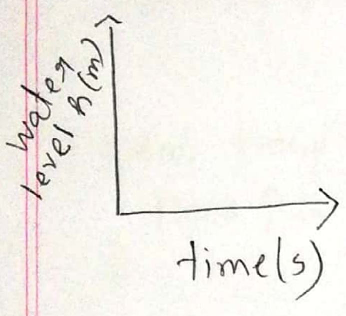
Open channel flow তে viscosity force এর চেয়ে gravity force বেশি dominant.



Irregular shape এর bed



manmade channel regular shape এর হয় (Rectangular, circular, parabolic ....). Natural channel irregular shape এর।

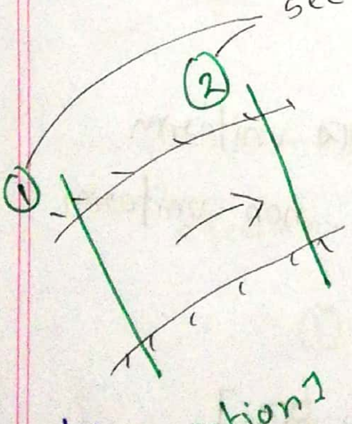


h = depth of flow/water level (m)

v = velocity of the flowing current (m/s)

Q = discharge (m^3/s or cfs)

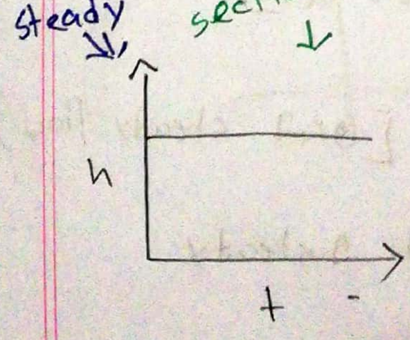
section নির্ণয়

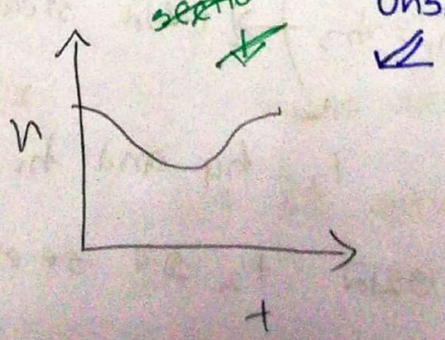


~~section~~ upstream/ ~~dow~~ downstream

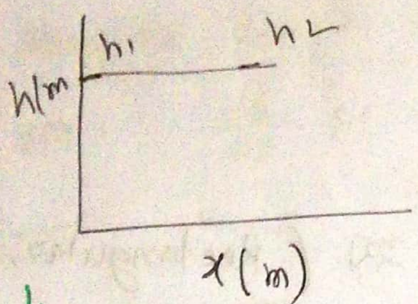
কোন particular location এর respect এ decide করা হয়

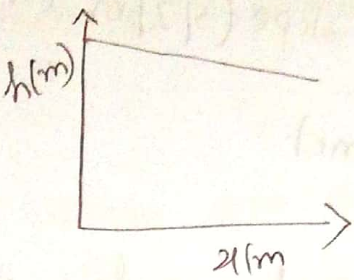
upstream (u/s) downstream (d/s)





(B)

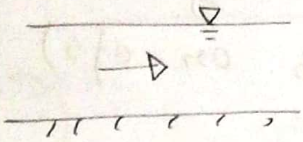




↓ uniform flow (space এর respect এ h same)

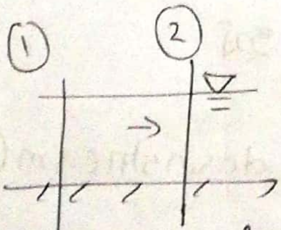
↓ non-uniform flow.

Steady flow:



Uniform flow → Laboratory তে occur

Non- " " → Natural channel এ occur



$h_1 = h_2$ হলে flow হবে uniform

$h_1 \neq h_2$ " " " non-uniform

$t_1 = h_1$ $t_1 = h_2$

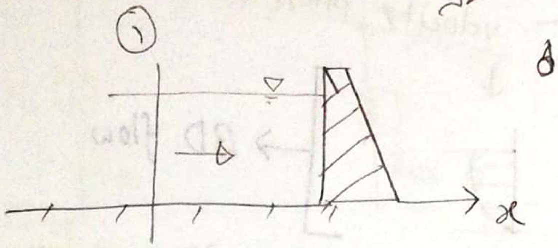
↓

$t_2 = h_3$ and $h_1 = h_3$ → [তখন steady flow হবে]

$t_2 = h_4$ and $h_1 = h_4$ [তখন steady flow]

$h_2 = h_4$ তখন t_2 এর so respect এ steady

: Uniform flow can be steady only [দুটো diff. location এ যেহেতু height নির্দিষ্ট water এর, তাই uniform flow always steady)



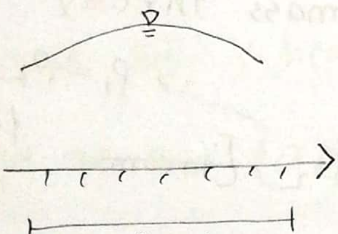
এখানে w.r.t. time depth change হয় ক্রমশ

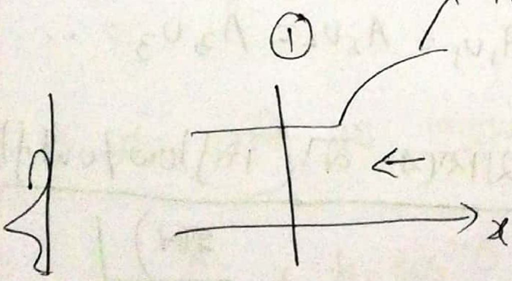
→ steady gradually varied flow.

tidal flow / flood flow → unsteady gradually varied flow

⇅

[sea এর কাছে variation বেশি tide এর জন্য; যত sea এর মাঝে যাব variation কমবে]





defⁿ, expression, example স্যারের বই থেকে

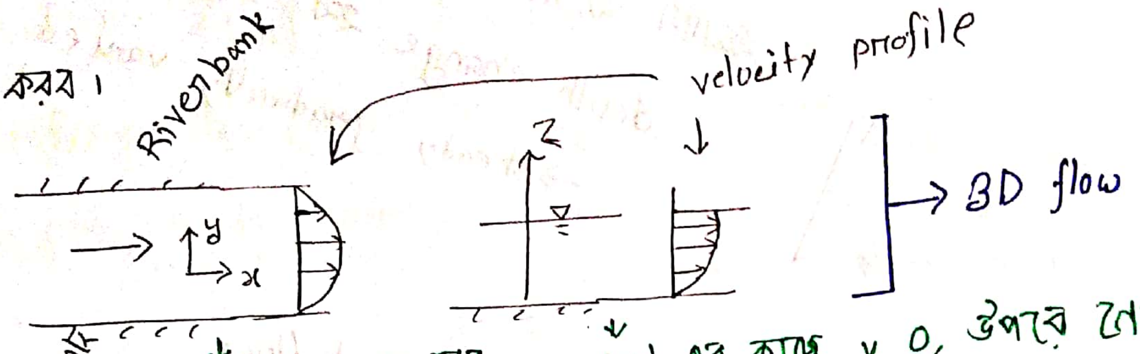
Halim sir এর বই ১ম chapter 1 এর article 1.4

Lec-03

25/02/2020

Steady 1-D flow:

Flow actually 3-D. But simplicity এর জন্য 1-D analysis করব।



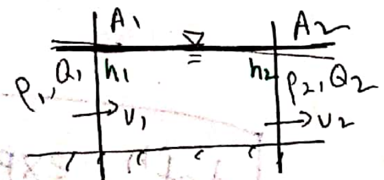
Bank থেকে যত দূরে, v বেশি,

bed এর কাছে v 0, উপরে গেলে বাড়বে

River width আর depth এর উপর depend করে কয় dimensional যেমন : width অনেক বেশি হলে 2D.

① Continuity eq^n:

— conservation of mass theory অনুযায়ী,



$h_1 = h_2$ same

$$\rho_1 Q_1 = \rho_2 Q_2$$ ~~[incom~~ → $\rho_1 = \rho_2$ [incom fluid]

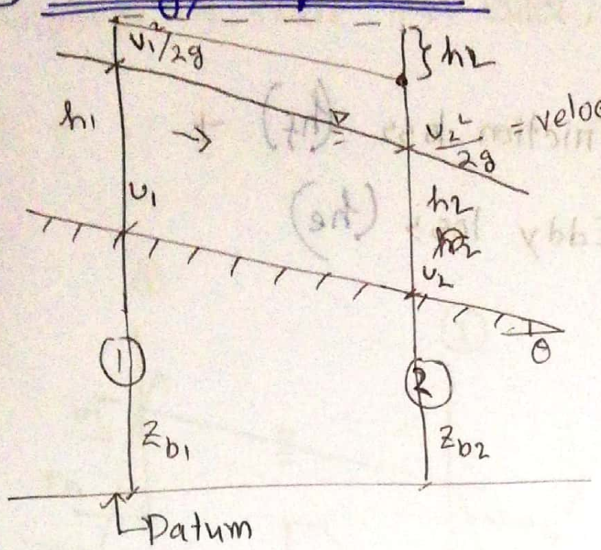
$$\Rightarrow Q_1 = Q_2$$

$$\Rightarrow A_1 v_1 = A_2 v_2 = A_3 v_3 = \dots$$

Discharge vary করলে uniform থাকবে না (inflow/outflow হলে)

~~h_1 আর h_2 এ~~

② Energy equation: [Bernoulli থেকে]



$$z_{b_1} + h_1 + \frac{v_1^2}{2g} = z_{b_2} + h_2 + \frac{v_2^2}{2g}$$

[∵ channel এ irregular boundary and rough এর জন্য velocity change হয়]

~~ban~~

Non-uniformity of the velocity থাকার জন্য v head কে co-eff. দিয়ে গুণ করা হয়। (α_1)

then,

$$z_{b_1} + h_1 + \alpha_1 \frac{v_1^2}{2g} = z_{b_2} + h_2 + \alpha_1 \frac{v_2^2}{2g}$$

θ যদি বেশি হয়, তাহলে pressure কে $\cos^2\theta$ দিয়ে গুণ।

$$z_{b_1} + h_1 \cos^2\theta + \alpha_1 \frac{v_1^2}{2g} = z_{b_2} + h_2 \cos^2\theta + \alpha_1 \frac{v_2^2}{2g}$$

head loss → (I) loss due to friction

(II) " " " the formation of eddy

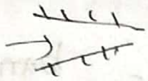
Total head loss, h_L = Friction loss (h_f) + Eddy loss (h_e)

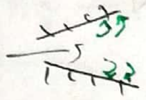
~~$h_E \propto$ magnitude~~

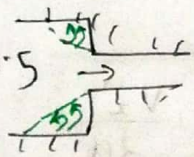
$$h_E \propto \left| \alpha_1 \frac{v_1^2}{2g} - \alpha_2 \frac{v_2^2}{2g} \right|$$

$$\therefore h_E = k_e \left| \alpha_1 \frac{v_1^2}{2g} - \alpha_2 \frac{v_2^2}{2g} \right|$$

K_e = eddy loss coefficient

$K_e = 0.1$  [gradual contraction]

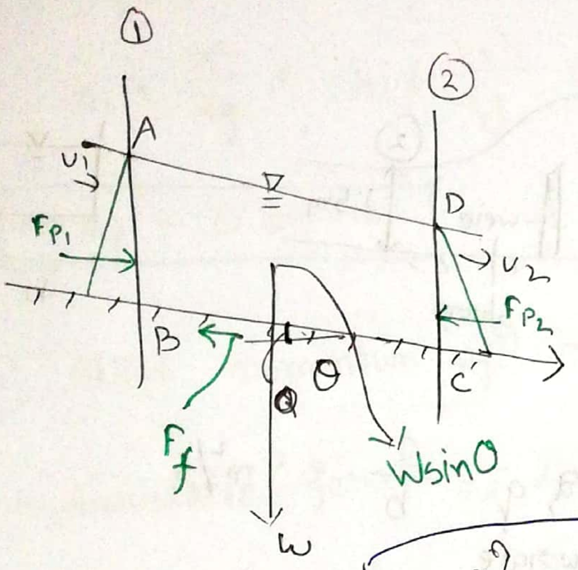
$K_e = 0.2$  [" expansion]

$K_e = 0.5$  [sudden contraction / expansion]

$v = \sqrt{2gh}$ ⇒ law of torricelli

(3) Momentum eq^n: [Newton's 2nd law of eq^n] থেকে এসেছে]

↳ sheet এ state করা আছে; দেখব।



F_{P_1} = hydraustatic force

F_f = frictional force

Momentum coeff = β
[velocity uniform না হই]

$\rho Q(u_2 - u_1)$

[uniform এ $v_1 = v_2$ তখন শুধু F_f আর $W\sin\theta$ থাকে] *

$$\rho Q(\beta_2 v_2 - \beta_1 v_1) = F_{P_1} - F_{P_2} - F_f + W\sin\theta$$

[1D steady flow eq^n]

- β = 1, velocity $dist^n$ uniform.

Energy eq^n থেকে যে velocity পাবো, সেটা scaler } dir consider না করলে same

But momentum eq^n এ vector [dir. imp.]

Steady uniform/steady gradually varied এ ~~scaler~~ Energy eq^n use করা হয় অনেক বেশি।

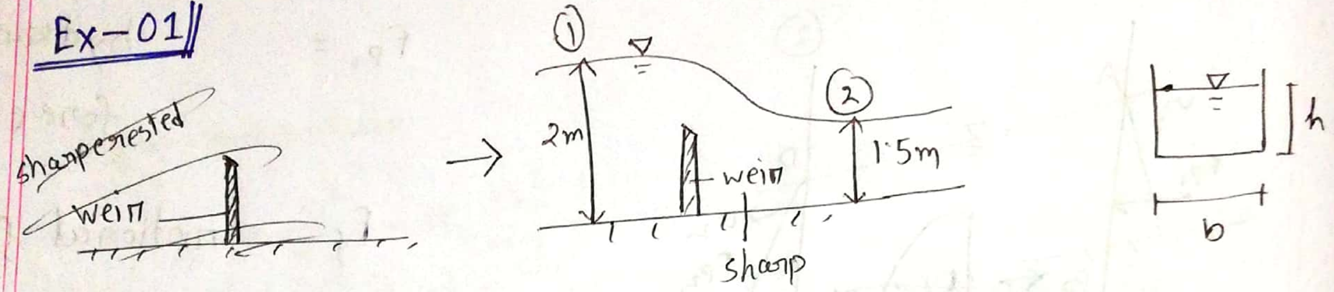
Canal এ obstruction নাই → uniform ধরব।

Lec-04

26/02/2020

Application: কখন কোন eq^n use করব বুঝতে হবে আগে।

Ex-01



A rectangular channel.

Discharge per unit width / a, $q = \frac{Q}{b} = 4 m^2/s$
flow rate

↓

unit m^2/s; যদি discharge এর unit এটা থাকে তাহলে flow rate বুঝব।

(a) ① and ② এর মাঝে energy loss কত?

(b) Force on weir? [কোন contraction, expansion নাই তাই eddy loss নাই। শুধু friction loss]

a এর মান থাকলে v head এর সাথে multiply করতে হবে

weir দুই ধরনের - sharp আর broad crested

Solnˢ

(a) $v_1 = \frac{q}{h_1} = 2\ m/s$ $v_2 = \frac{q}{h_2} = 2.67\ m/s$

Applying energy eqⁿ in between section ① and ②

$$h_1 + \frac{v_1^2}{2g} = h_2 + \frac{v_2^2}{2g} + h_f$$

$\Rightarrow h_f = 0.34\ m$

(b) এখানে momentum eqⁿ ~~all~~ apply করা হবে।

Hydraustatic force $= \frac{1}{2}\gamma h^2$

Applying momentum eqⁿ in between section ① and ②.

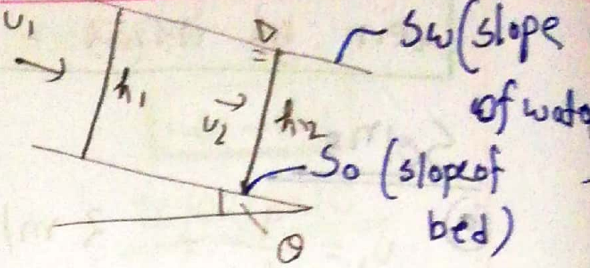
$$\rho q(v_2 - v_1) = \frac{1}{2}\gamma h_1^2 - \frac{1}{2}\gamma h_2^2 - F$$

~~⇒ F =~~

$\Rightarrow F = 5903.75\ N$ → এটা per unit width এ

weir এর width দেওয়া থাকলে ans এ width multiply হবে

$S_w, S_o,$



Uniform flow:

From momentum eqⁿ:–

$$\rho Q(\beta_2 u_2 - \beta_1 u_1) = F_{p_1} - F_{p_2} - F_f + W\sin\theta$$

$S_o = S_w$

$h_1 = h_2$

$\therefore u_1 = u_2$

$\therefore F_{p_1} = F_{p_2}$

$$\Rightarrow 0 = -F_f + W\sin\theta$$

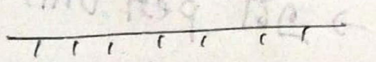
$$\Rightarrow \boxed{F_f = W\sin\theta}$$

S_w, S_o parallel হলে friction line draw করলে তার slope

ও 3 parallel. $\boxed{S_f = \text{friction slope / energy slope}}$

~~For~~ uniform flow To be the conditions:

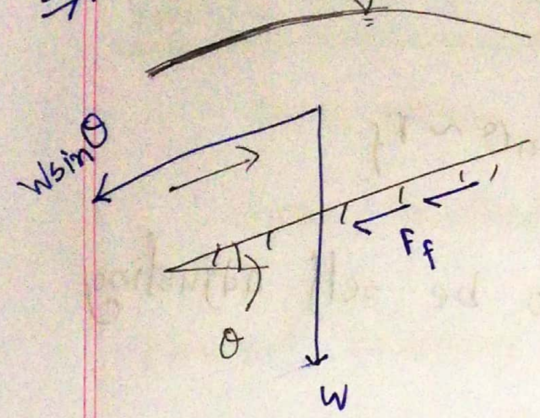
#



$S_0 = 0$

তখন $W\sin\theta$ 0 হয়ে যায়। মানে F_f ও 0। তাই

horizontal sloped channel এ uniform flow is not possible.



তাই adverse slope channel এও uniform flow possible না (eq^n অনুযায়ী)

Frictionless channel এ flow uniform হবে না।

Ideal fluid frictionless; " " " "

uniform flow normally natural water ways এ possible না (irregularity of section এর জন্য)

<u>Varied flow তে:</u>

$W\sin\theta > F_f$ [Flow is accelerated; মানে friction কম তাই water velocity বাড়ছে]

$F_f \propto v^2$; u increase করলে F_f ও বাড়বে। F_f আস্তে আস্তে $W\sin\theta$ এর সমান হওয়ার চেষ্টা করবে।

$W\sin\theta \sim F_f$ [uniform হওয়ার চেষ্টা করবে]

$W\sin\theta < F_f$ [Flow will be retarded]

velocity of flow কমবে; $F_f \propto v^2$; F_f ও কমবে; $W\sin\theta$

এর কাছে যাওয়ার try করবে।

$$v\downarrow \longrightarrow F_f \propto v^2 \longrightarrow F_f \downarrow — W\sin\theta \sim F_f$$

Thus, the uniform flow seems to be self adjusting

$$\boxed{W\sin\theta \approx F_f}$$

Lee-05

1/03/2020

Velocity distribution:

boundary → bed আর side slope এর roughness এর জন্য non-uniformity in velocity dis^n আসে।

velocity কে predict করতে চাইলে boundary roughness কে devide করা হয় →

Smooth + transition + Rough boundary

Shear stress:

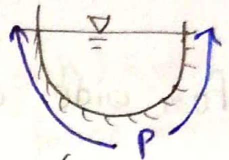
Difference → water যে flow করছে তা boundary এর সাথে একটা force এর মত কাজ করে।

friction force f_f = Shear force

Velocity disn in uniform flow:

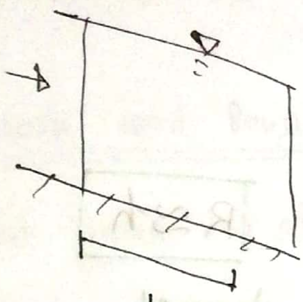
Shear stress, τ_0

Shear / traction/ drag force $= \tau_0 PL$



channel boundary এর যতটুকু পানির contact এ থাকে, wetted perimeter বলে থাকে (P)

long section



cross section

$P \times L = \text{Area}$ — not cross sectional area

$F_f = \tau_0 PL$

for uniform flow,

$w \sin\theta = PL \times \tau_0$

$\Rightarrow \gamma A L S_0 = \tau_0 P L$

$\Rightarrow \tau_0 = \frac{\gamma A}{P} S_0$ ← S_0: Bottom slope

$$\tau_0 = \frac{\gamma A}{P} S_0$$

$w = \gamma A L$ — A: cross-section area

θ small, in radian

$\sin\theta \approx \tan\theta \approx \theta$

$\tan\theta = S_0$

large slope হলে ignore করা যাবে না

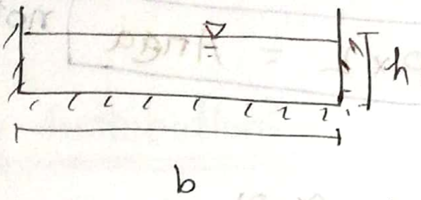
$\cos^2\theta$ দিয়ে multiply আরো $\theta \geq 6^\circ$ এর জন্য

Hydraulic radius, $R = \frac{A}{P}$ A = cross section area

$$\therefore \tau_0 = \gamma R S_0 = \rho g R S_0$$

For wide channel (normally rectangular ধরা হয়)

wide channel হলে depth to width অনেক vary করে।



$$R = \frac{A}{P} = \frac{b \times h}{b + 2h} \approx \frac{bh}{b} \approx h$$

$2h$ → negligible for wide channel

$$R \approx h$$

$$\therefore \tau_0 = \rho g R S_0 = \rho g h S_0$$

Friction velocity / Shear / drag velocity: (u^* → designation)

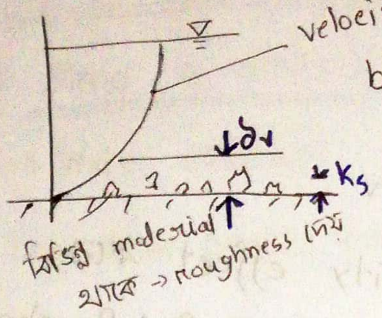
$$u^* = \sqrt{\frac{\tau_0}{\rho}}$$ [distance travelled per unit time → unit]

$$= \sqrt{\frac{g \rho R S_0}{\rho}}$$

$$\therefore u^* = \sqrt{g R S_0}$$

$$u^* = \sqrt{g h S_0}$$ → wide channel

Laminar / Viscous sub-layer:



boundary এর কাছাকাছি thin layer থাকে (natural channel এ) যেখানে laminar flow থাকে → Laminar / viscous sublayer.
viscous force dominant.

Thickness of this laminar sub-layer, $\delta_v = \frac{11.6\nu}{u^*}$ $\left(\frac{m^2/s}{m/s} = m\right)$

Smooth and Rough boundary:

sand grain → standard ধরে নেয়া হয়েছে → এর সাপেক্ষে অন্য mat. এর roughness express করা হয়। → তখন বলবে equivalent sand grain roughness.

Nikuradse propose করেছে

→ Equivalent sand grain roughness, k_s

Relative roughness $= \frac{K_s}{R}$

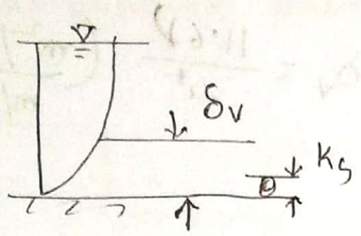
glass এ → .002 mm
cast iron → 0.26
Concrete → 0.3 – 3

} K_s এর value

Classification of boundary surface:

(i) Hydraulically Smooth Boundary:

$$\frac{u^* k_s}{\nu} \leq 5 \quad \text{and} \quad k_s < \delta_v$$



viscosity effect করে velocity disn এ ; Roughness করে না।

(ii) Hydraulically Rough boundary:

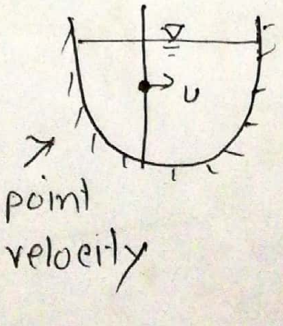
viscosity effect করে না ; Roughness করে।

$$\frac{u^* k_s}{\nu} \geq 70 \quad \text{and} \quad \delta_v < k_s$$

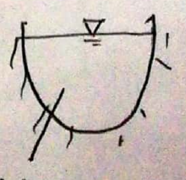
(iii) Transition:

$$5 < \frac{u^* k_s}{\nu} < 70$$

viscosity আর Roughness দুটোর ই effect আছে



u বের করতে হলে 1st এ দেখাতে হবে Boundary smooth নাকি rough.



U → cross sectional velocity (capital U)

Lec—06

C.T. 03/03/2020

Velocity Distribution in turbulent flow:

Along a vertical:

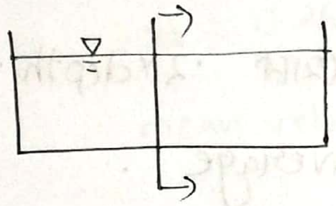
→ Wide channel

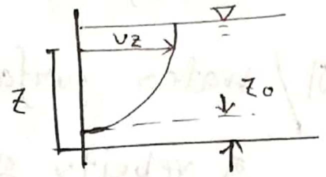
log flow profile follow করে।

$$\frac{u_z}{u^*} = \frac{1}{K} \ln \frac{z}{z_0}$$

u_z = velocity along a vertical at a distance z from channel bottom

K = von-Karman constant (.4). z_0 = zero velocity level ($u=0$, $z=z_0$)





z_0 এর value এর জন্য emperical eqn আছে (~~Roung~~ Roughness এর উপর depend করে)

~~Smooth~~ ① Hydraulically smooth boundary →

$$\frac{u^* k_s}{\nu} \leq 5$$

k_s = equivalent sand grain roughness

$$z_0 = 0.11 \frac{\nu}{u^*} \quad \text{(unit m)}$$

② Hydraulically Rough boundary:

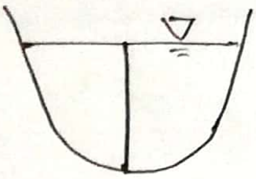
$$\frac{u^* k_s}{\nu} \geq 70 \qquad \therefore z_0 = 0.033 k_s$$

③ Transition boundary:

$$z_0 = 0.11 \frac{\nu}{u^*} + 0.033 k_s$$

Depth avg velocity:

(যেকোন channel এর ~~যেকোন একটা~~ ~~point এ depth measure করলে~~ ·6 × depth from water surface এ যে velocity পাবো।



বা/ water surface থেকে ·2 × depth + ·8 depth এ velocity এর average.

Cross-sectional velocity: U (capital v)

Boundary roughness এর উপর depend

Smooth boundary → $\frac{U}{u^*} = 5.75 \log\left(\frac{3.64 u^* R}{\nu}\right)$

Rough " → $\frac{U}{u^*} = 5.75 \log\left(\frac{12.2 R}{k_s}\right)$

Transitional " → $\frac{U}{u^*} = 5.75 \log\left(\frac{12.2 R}{k_s + 3.35 \frac{\nu}{u^*}}\right)$

Scanned with CamScanner

u^* physically exist করে না। $\frac{u}{u^*}$ করা হয় dimensionless quantity পাওয়ার জন্য।

Non-dimensional এর জন্য wide range of application করা যায়।

Relationship coefficient যত 1 এর কাছাকাছি, দুটো parameter এর relation তত ভালো বুঝাবে।

Problem

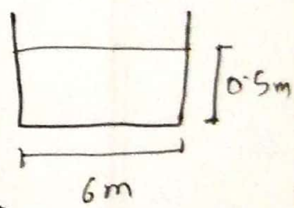
Ex-1: Rectangular channel, Bottom width $= 6\,m$, depth of flow, $h = 0.5\,m$

$S_0 = 0.25\%$, $k_s = 2\,mm$

mean velocity, $u = ?$

$\nu = 10^{-6}$ assume করব value না থাকলে

1st এ কেমন boundary define করতে হবে।



$$\frac{u^* k_s}{\nu} = 205 > 70$$

$$u^* = \sqrt{gRS_0} = .1025\ m/s$$

$$R = A/P = 0.43\,m$$

$$A = bh = 3\,m^2$$

$$P = 6 + 0.5 + 0.5 = 7\,m$$

Hydraulically Rough boundary

$$\frac{u}{u^*} = 5.75 \log\left(\frac{12.2R}{k_s}\right)$$

$$\Rightarrow u = 2.0169\ m/s$$

Ans

Uniform flow formula:

① Chezy Formula: $W\sin\theta = F_f$

~~1st assumption:~~

$W\sin\theta = \gamma A L \sin\theta$

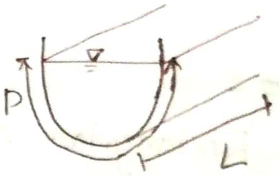
যেহেতু uniform flow তে S_0, S_f parallel

$\Rightarrow W\sin\theta = \gamma A L S_0 = \gamma A L S_f$ —— (I)

$F_f \propto v^2$

$F_f = K PL v^2$ —— (II)

Total F_f বের করার জন্য area গুণ



PL = Area

~~(I) = (II)~~ From (I) and (II),

$\gamma A L S_f = K P L v^2$

$\Rightarrow v^2 = \frac{\gamma}{K} \frac{A}{P} S_f$

$\Rightarrow v = C R^{1/2} S_f^{1/2}$, C = Chezy constant $= \sqrt{\frac{\gamma}{K}}$

[depent করে unit এর উপর

$(30 \sim 80\ m^{1/2}/s) \Rightarrow$ BD তে value in SI unit

$Q = Av$

$= C A R^{1/2} S_f^{1/2}$

Formula is applicable for uniform flow

~~Eng~~