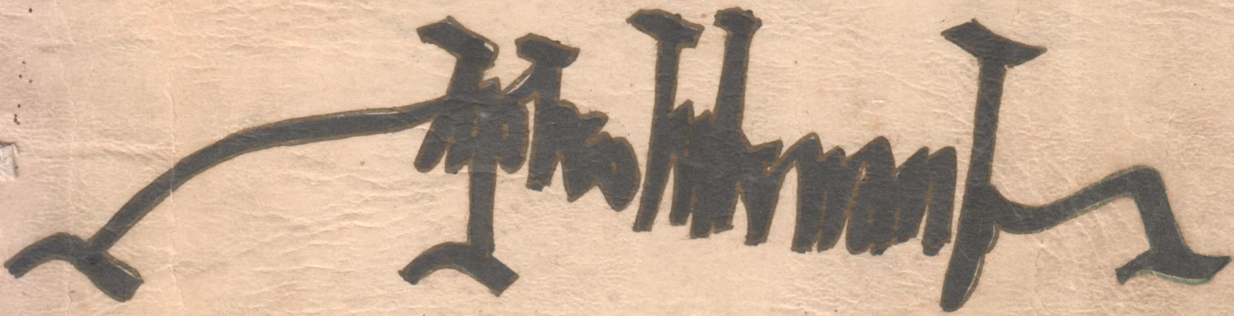
kuliah Open Channel Flow



1983

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Open Channel Flow

Macam pengaliran pd sal. terbuka ditinjau dari :

A. Aspek waktu

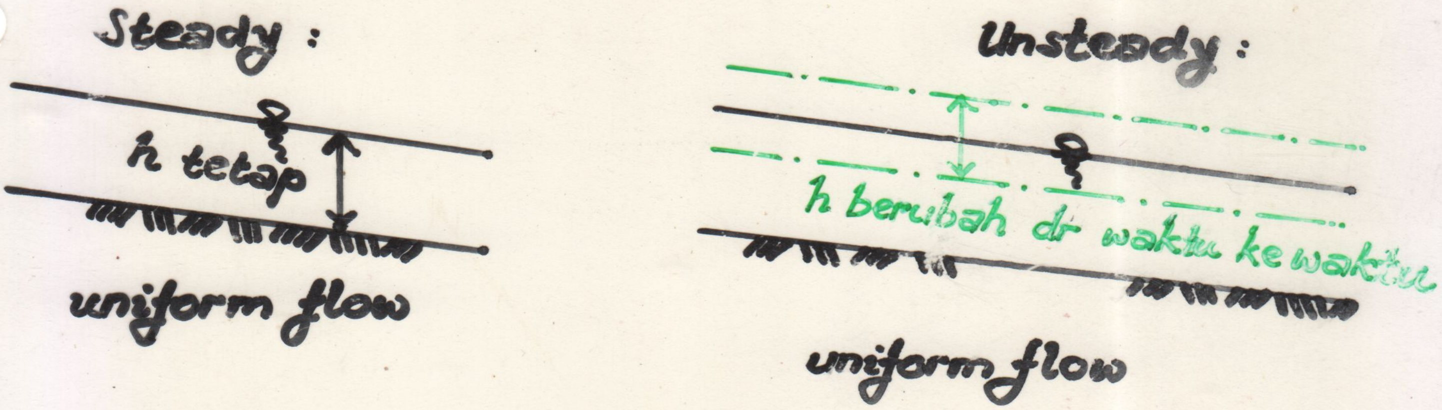
1. Pengaliran Langgeng / Permanen / Steady flow.
2. Pengaliran tidak Langgeng / Unsteady flow.

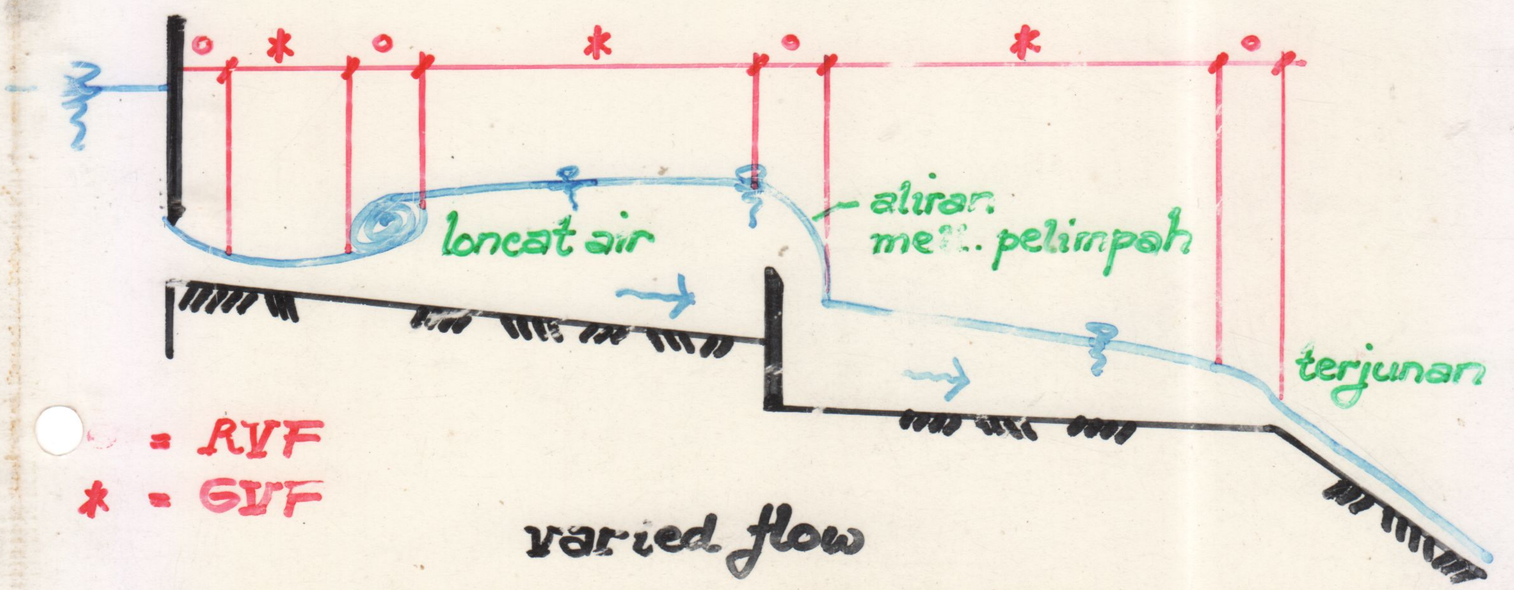
B. Aspek ruang.

1. Pengaliran beraturan / Uniform flow
2. Pengaliran tidak beraturan / Varied flow :
   a. Gradually Varied Flow (GVF)
   b. Rapidly Varied Flow (RVF)

C. Aspek kecepatan rata² ($\bar{u}$)

1. Mengalir : $\bar{u} < u_{kr}$
2. Kritik : $\bar{u} = u_{kr}$
3. Meluncur : $\bar{u} > u_{kr}$





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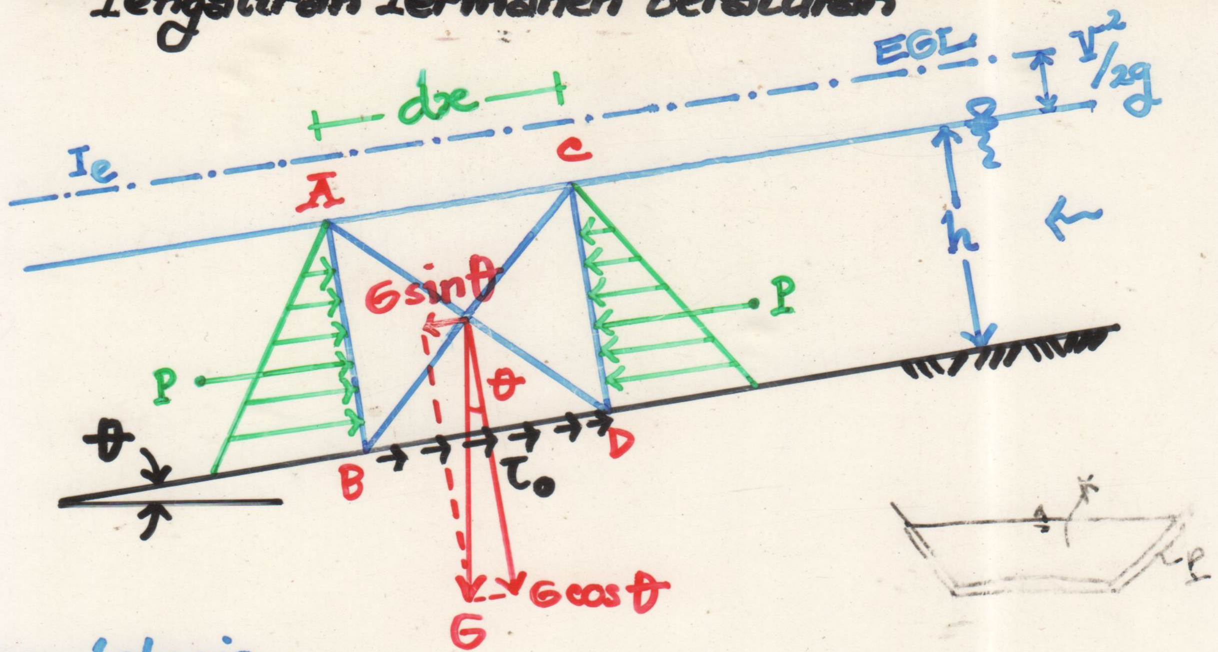
Pengaliran Permanen Beraturan



Gaya² yg bekerja :

1. Gaya pendorong :
   - gaya tekanan pada AB & CD → saling meniadakan
   - gaya tek. atmosfir ⊥ gerak → tidak berpengaruh
   - berat massa air
2. Gaya penghambat :
   - geseran pada dinding : τ_o → fungsi dari $\bar{u}$

Steady Uniform Flow :

Gaya pendorong = gaya penghambat

$$G \sin\theta = P.dx.\tau_o$$

$$A.dx.\gamma \sin\theta = P.dx.\tau_o$$

$$\frac{A}{P}.\rho g.\sin\theta = \tau_o$$

Jadi : $$\tau_o = \rho g R I_e$$

atau

$$R I_e = \frac{\tau_o}{\rho g} \rightarrow \text{fungsi dr } \bar{u}$$

$$\varphi(\bar{u})$$

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dimana I_e = kemiringan grs energi (EGL)
R = radius hidrolik = A/P
A = luas penampang basah
P = keliling basah
τ_o = gaya geser tiap satuan luas dinding
ρ = rapat massa air
g = grafitasi bumi
γ = ρg = berat jenis air
Jika θ kecil maka $I_e = \sin\theta \rightarrow I_e = tg\,\theta$

Kecepatan rata² ($\bar{u}$)

1. Menurut De Chezy (1775)

$$R I_e = \varphi(\bar{u})$$
$$= \frac{\bar{u}^2}{C^2} \quad \text{shg} \quad \boxed{\bar{u} = C\sqrt{R I_e}}$$

C = koef. chezy ($L^{1/2} T^{-1}$) → metrik : $m^{1/2}/det$

2. Menurut Gauckler - Manning (1890)

$$\boxed{\bar{u} = \frac{1}{n} R^{2/3} I^{1/2}} \rightarrow \text{metrik}$$

3. Menurut Strickler

$$\boxed{\bar{u} = K_s R^{2/3} I^{1/2}} \rightarrow \text{metrik}$$

dimana
n = koef. kekasaran Manning
K_s = koef. kekasaran Strickler

Tampak bahwa $K_s = \frac{1}{n}$

$C = K_s R^{1/6} \rightarrow$ utk $R = 1$
$C = K_s$

④

Macam² rumus utk menghitung c :

- Kutter
  $c = f(m, R)$
- Ganggquillet - Kutter (1869)
  $c = f(n, R, I)$
- Bazin
  $c = f(\gamma_B, R)$
- Thysse
  $c = f(a, R, \delta)$

(lihat diktat !)

Semua rumus diatas adalah sama yg penting adalah ke tepatan memperkirakan m, n, γ_B, K_s, a, yang paling m dah adalah a karena tampak oleh mata.

Pembagian Kecepatan pd suatu Vertikal

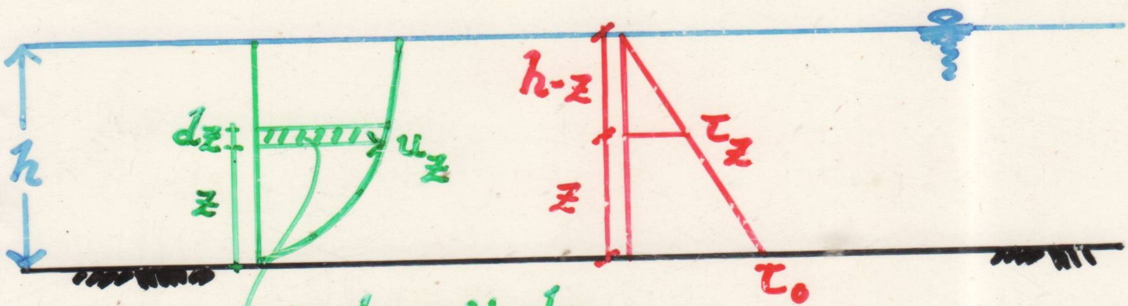
1. Utk pengaliran laminer → $Re' = \frac{\bar{u}R}{\nu} < 500$

I. Persamaan Laminer Flow (Newton)

Teg. gesek : $\tau_z = \mu \frac{du_z}{dz}$

II. Persamaan Steady Uniform flow.

Tegangan gesek : $\tau_z = \rho g (h-z) I$ → utk $B = \infty$; $R =$



$dq = u_z dz$

$I = II$: $\mu \frac{du_z}{dz} = \rho g (h-z) I$

$$du_z = \frac{gI}{\mu/\rho}(h-z)dz$$

$$u_z = \int du_z$$

$$= \int \frac{gI}{\nu}(h-z)\,dz \rightarrow u_z = \frac{gI}{\nu}\left(hz - \frac{1}{2}z^2 + c\right)$$

Syarat batas : $z = 0 \rightarrow u_z = 0$; jadi $c = 0$, sehingga

$$\boxed{u_z = \frac{gI}{\nu}\left(hz - \frac{1}{2}z^2\right)} \rightarrow \text{parabola !!!!}$$

Kecepatan rata² pada suatu vertikal :

q = debit tiap satuan lebar saluran $= \frac{Q}{B}$

$dq = u_z\,dz$

$$q = \int_0^h \frac{gI}{\nu}\left(hz - \frac{1}{2}z^2\right) dz$$

$$= \frac{gI}{\nu}\left[\frac{1}{2}hz^2 - \frac{1}{6}z^3\right]_0^h \rightarrow q = \frac{gI}{\nu}\frac{h^3}{3} \quad \ldots (1)$$

$$\bar{u} = \frac{q}{h} \quad \ldots (2)$$

Jadi a. Utk $B = \infty \rightarrow \bar{u} = \frac{gI}{3\nu}h^2$

b. Utk $B \neq \infty \rightarrow \bar{u} = \frac{gI}{3\nu}R^2$

B. Utk pengaliran turbulen $\rightarrow Re' = \frac{\bar{u}R}{\nu} > 600$

Menurut Prandtl : $\tau_z = \rho l^2 \left(\frac{du_z}{dz}\right)^2$

dimana l = mixing length

$= \varkappa z$ ($\rightarrow$ linear)

↳ kappa = konstanta universal von Karman

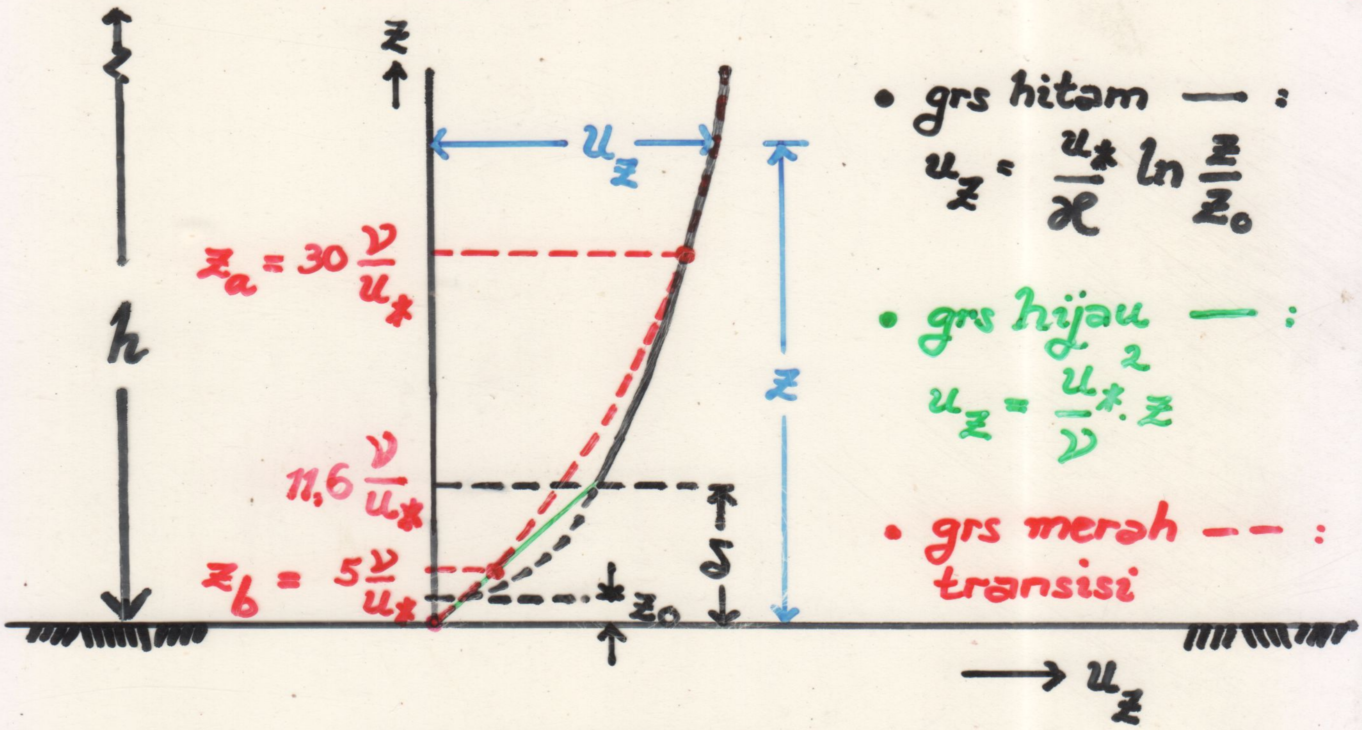
$= 0{,}4$

Asumsi : didekat dasar $\tau_z = \tau_0$

$$\rho \varkappa^2 z^2 \left(\frac{du_z}{dz}\right)^2 = \rho g h I$$

$$\frac{du_z}{dz} = \frac{\sqrt{ghI}}{\varkappa} \cdot \frac{1}{z} \rightarrow u_z = \int_{z_0}^{z} \frac{\sqrt{ghI}}{\varkappa} \frac{dz}{z}$$

Jadi $$u_z = \frac{u_*}{\varkappa} \ln \frac{z}{z_0}$$ → hk pembagian kecep. universal Prandtl - von Karman !!!



Walaupun rumus diatas dijabarkan dekat dasar, tetapi percobaan menunjukkan bahwa rumus diatas berlaku pada seluruh kedalman (h)

Rumus diatas berlaku utk aliran turbulen, maka pd daerah batas laminer δ rumus tidak berlaku, krn dilapisan batas laminer gaya viskositas lebih penting.

Untuk daerah batas laminer rumus dijabarkan sbb :

I. $\tau_z = k \frac{du_z}{dz}$ II $\tau_0 = \rho g h I = \rho u_*^2$

(7)

Asumsi dilapisan batas laminer $\tau_z = \tau_o$ = tetap, shg

$$du_z = \frac{\tau_o}{\mu} dz$$

$$= \frac{u_*^2}{\mu/\rho} dz \rightarrow du_z = \frac{u_*^2}{\nu} dz$$

Jadi $$\boxed{u_z = \frac{u_*^2}{\nu} z}$$

↳ tetap untuk kondisi tertentu

Pada batas daerah laminer dimana $z = \delta$, maka

$$u_{z=\delta} = \frac{u_*^2 \delta}{\nu}$$

$$= \frac{u_*^2}{\nu} \cdot \frac{11{,}6\,\nu}{u_*} = 11{,}6\, u_*$$

Catatan: Sesungguhnya tidak terdpt perubahan mendadak pada batas laminer yi dr log ke linier, melainkan suatu transisi dari batas atas $z_a = 30 \frac{\nu}{u_*}$ ke batas bawah $z_b = 5 \frac{\nu}{u_*}$

Harga z_o :

A. Hidrolik licin $(a \ll \delta/7)$

$$z_o = \frac{\delta}{100 \text{ à } 104} \quad \text{dimana } \delta = \frac{11{,}6\,\nu}{u_*} = \frac{11{,}6\,\nu}{\sqrt{gRI}} = \frac{11{,}6\,\nu}{\sqrt{\tau_o/\rho}}$$

↳ biasa dipakai di Indonesia.

$$u_z = \frac{u_*}{\varkappa} \ln \frac{z}{z_o} = \frac{u_*}{0{,}4} \cdot 2{,}3 \cdot \log \frac{104\, z}{\delta}$$

$$\therefore \boxed{u_z = 5{,}75\, u_* \log \frac{104\, z}{\delta}} \rightarrow \text{kecep. titik}$$

$$\boxed{\bar{u} = u_{z=0{,}4h} = 5{,}75\, u_* \log \frac{42h}{\delta}} \rightarrow \text{kecep. rata}^2$$

B. Hidrolik kasar $(a \gg \delta/7)$

$$z_0 = \frac{k}{30 \text{ a } 33}$$

↳ AS ↳ Eropa

dimana $k = 2a$

↳ jari² butiran dinding / kekasaran

$$u_z = \frac{u_*}{0{,}4} \ln \frac{33z}{k} \rightarrow \text{kecep. titik}$$

$$\bar{u} = u_{z=0{,}4h} = 5{,}75\, u_* \log \frac{12h}{k} \rightarrow \text{kecep. rata}^2$$

Oleh Colebrooke & White kedua rumus kecep. rata² digabung sbb :

Hidrolik licin : $\bar{u} = 5{,}75\, u_* \log \dfrac{12h}{2\,\delta/7}$ } digabung

Hidrolik kasar : $\bar{u} = 5{,}75\, u_* \log \dfrac{12h}{k}$

$$\bar{u} = 5{,}75\, u_* \log \frac{12h}{k + 2\,\delta/7} = 5{,}75 . \sqrt{gRI} . \log \frac{12h}{k + 2\,\delta/7} \quad \ldots .(1)$$

$$\bar{u} = C\sqrt{RI} \quad \ldots .(2)$$

dari (1) & (2) $\quad C = 5{,}75 . \sqrt{g} . \log \dfrac{12h}{k + 2\,\delta/7}$

Umum berlaku :

$$C = 18 \log \frac{12R}{k + 2\,\delta/7}$$

$$C = 18 \log \frac{6R}{a + \delta/7}$$

Hidrolik licin $\delta/7 \ggg a \rightarrow$ a diabaikan

Hidrolik kasar $a \ggg \dfrac{\delta}{7} \rightarrow \delta/7$ diabaikan

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Catatan :

Lapisan batas laminer $\delta = \frac{11,6\,\nu}{u_*}$

$\nu = \frac{\mu}{\rho} \rightarrow$ tergantung suhu air !

dimana :

μ = kekentalan dinamik $(ML^{-1}T^{-1}) \rightarrow N\,sec/m^2$

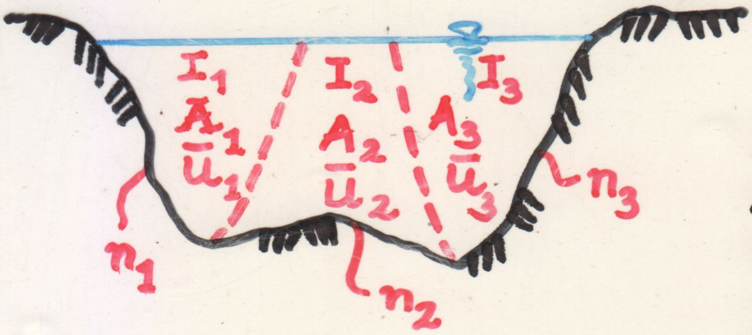
ρ = rapat massa $(ML^{-3}) \rightarrow kg/m^3$

ν = kekentalan kinematik $(L^2T^{-1}) \rightarrow m^2/det$

Harga ν :

suhu $t\,°C$:	0	10	20	30
ν $(10^{-6}\,m^2/det)$	1,8	1,3	1,0	0,8

Composite Roughness Formula (Einstein 1942)



Tiap pias saluran punya

I = kemiringan grs energi

A = luas pias

$\bar{u}$ = kecepatan rata²

n = koefisien Manning

P = kell. basah

Anggapan : $\bar{u}_1 = \bar{u}_2 = \bar{u}_3 = \bar{u}_{co}$; $I_1 = I_2 = I_3 = I_{co}$

$$\bar{u} = \frac{1}{n} R^{2/3} I^{1/2}$$

$$R = \left(\frac{n\bar{u}}{I^{1/2}}\right)^{3/2} \longrightarrow R_i = \frac{n_i^{3/2}\,\bar{u}_i^{3/2}}{I_i^{3/4}}$$

$$A_1 = R_1 P_1$$

$$\vdots$$

$$A_n = R_n P_n$$

$$\sum_{i=1}^{n} A_i = \sum_{i=1}^{n} (R_i P_i)$$

$$A_{co} = \sum_{i=1}^{n} \left(\frac{n_i^{3/2}\, \bar{u}_i^{3/2}\, P_i}{I_i^{3/4}} \right)$$

$$= \sum_{i=1}^{n} \left(\frac{n_i^{3/2}\, \bar{u}_{co}^{3/2}\, P_i}{I_{co}^{3/4}} \right)$$

$$= \frac{\bar{u}_{co}^{3/2}}{I_{co}^{3/4}} \sum_{i=1}^{n} \left(n_i^{3/2} P_i \right) \quad \ldots\ldots (I)$$

$$A_{co} = R_{co} P_{co}$$

$$= \left(n_{co}^{3/2}\, \bar{u}_{co}^{3/2}\, P_{co} \right) \cdot I_{co}^{-3/4} \quad \ldots\ldots (II)$$

$I = II$;

$$n_{co}^{3/2} P_{co} = \sum_{i=1}^{n} \left(n_i^{3/2} P_i \right)$$

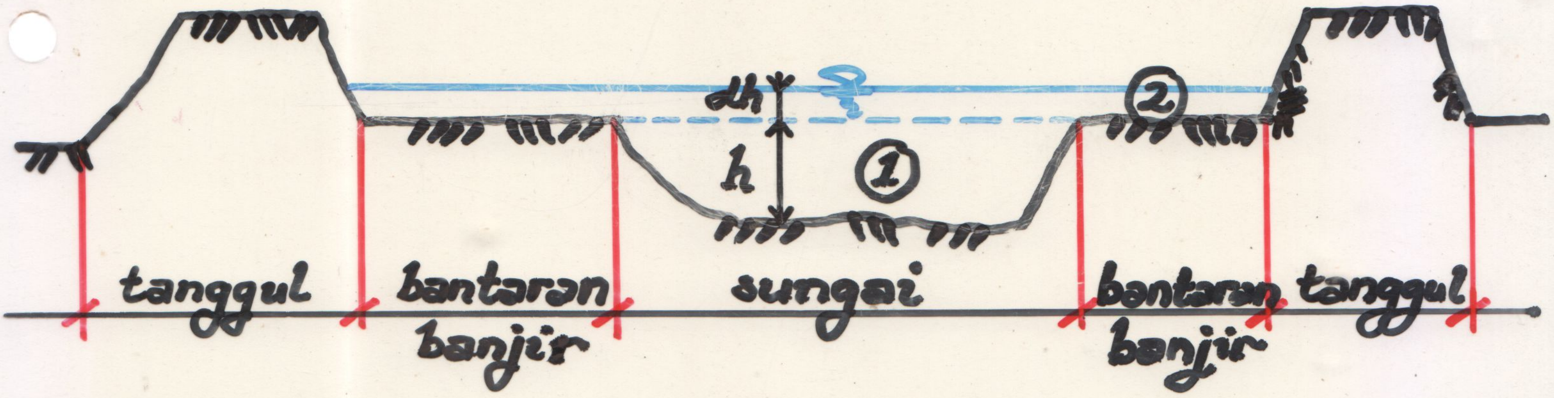
Jadi

$$n_{co} = \left\{ \frac{\sum_{i=1}^{n} \left(n_i^{3/2} P_i \right)}{P_{co}} \right\}^{2/3}$$

n_{co} = koef. manning composite

P_{co} = kell. basah composite

Profil Tersusun



Keadaan :	tinggi air :	luas :	kell. bsh :	radius hdrlk
Bank full Stage	h	A	P	R
Banjir	$h+dh$	$A+dA$	$P+dP$	R'

Jadi pada keadaan banjir :

$$R' = \frac{A+dA}{P+dP} \rightarrow R' = \frac{A}{P}\left\{\frac{1+\frac{dA}{A}}{1+\frac{dP}{P}}\right\}$$

dimana $\frac{dP}{P} \ggg \frac{dA}{A}$

sehingga $R' = R\left\{\frac{1}{1+\frac{dP}{P}}\right\} \rightarrow R' < R$

$\rightarrow \bar{u}' < \bar{u}$

Adalah tidak mungkin $\bar{u}$ banjir lebih kecil dp $\bar{u}$ keadaan normal.

Hal ini disebabkan karena adanya anggapan bahwa $\bar{u}$ pada (1) & (2) sama, pd hal tidak. Maka pada profil tersusun pendekatannya harus lain.

Harus disesuaikan dg profil tersusun (lihat diktat)