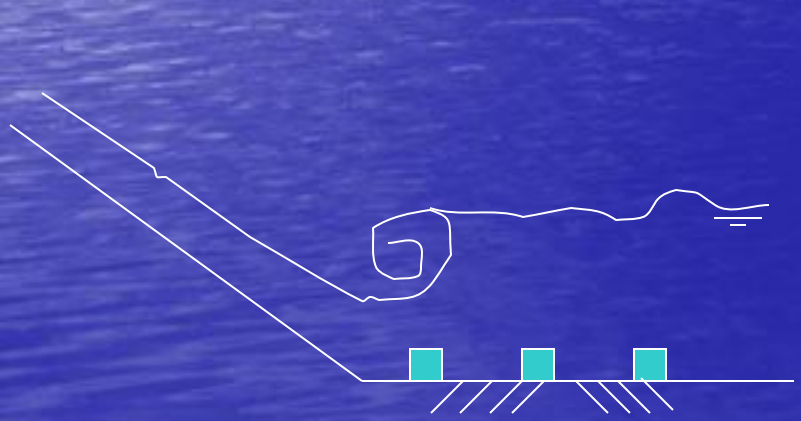
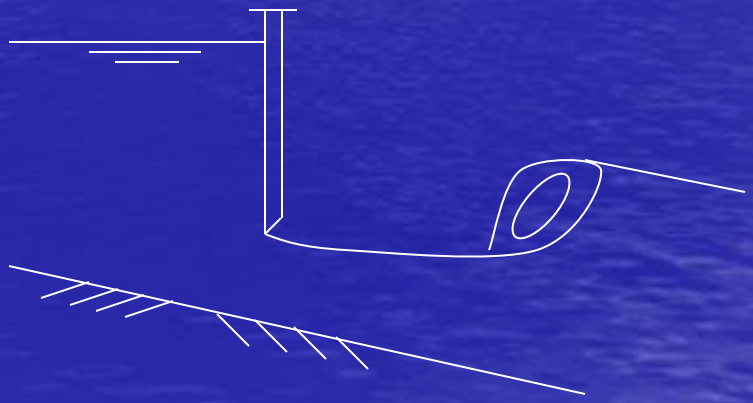
LONCAT AIR (HYDRAULICS JUMP)

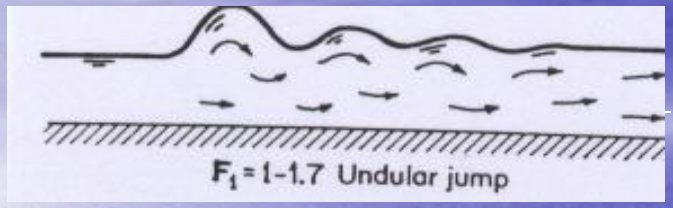
- Terjadi apabila suatu aliran *superkritis* berubah menjadi aliran *subkritis*, akan terjadi pembuangan energi.
- Konsep hitungan loncat air sering dipakai pada perhitungan bangunan peredam energi
  - di sebelah hilir bangunan pelimpah
  - di sebelah hilir pintu air





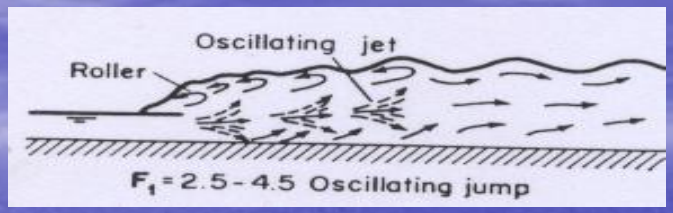
TYPE LONCAT AIR

- Undular jump



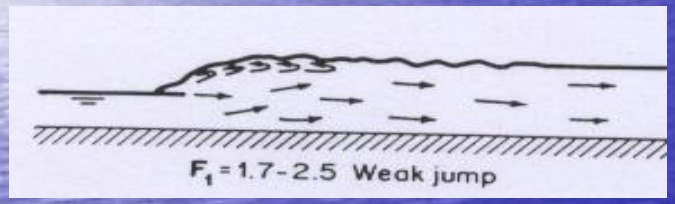
Fr = 1.00 – 1.70

- oscilating jump



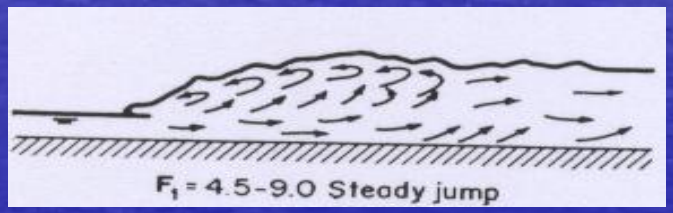
Fr = 2.50 – 4.50

- Weak jump



Fr = 1.70 – 2.50

- steady jump



Fr = 4.50 – 9.00

- Strong jump

Fr > 9.00

- Fr = 1,00 – 1,70

Perubahan aliran superkritis menjadi subkritis terjadi secara tiba-tiba, terlihat deretan gelombang berombak dipermukaan air (*Undular Jump*).

- Fr = 1,70 – 2,50

Gelombang pada permukaan (loncat air) mulai pecah, loncat air masih lemah (*weak jump*).

- Fr = 2,50 – 4,50

Terjadi osilasi (*oscillating jump*), loncat air dengan gelombang di belakangnya.

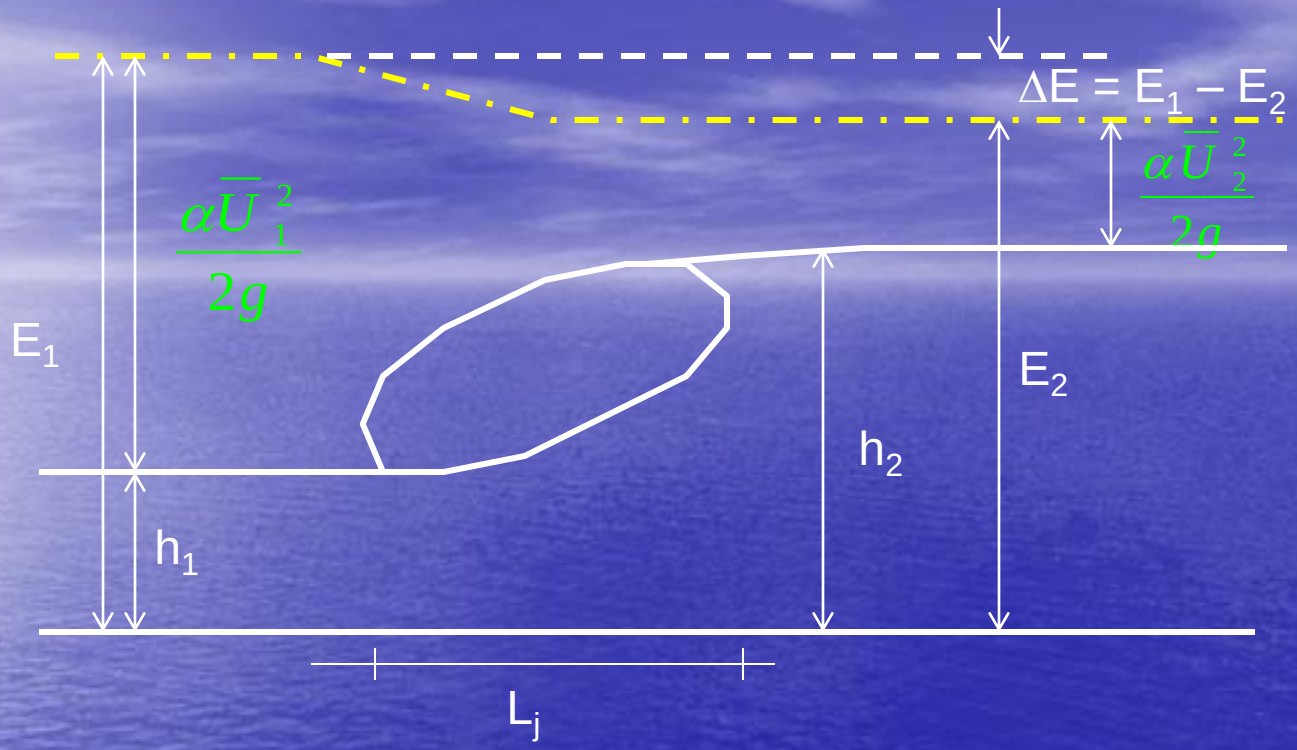
- Fr = 4,50 – 9,00

Loncatan yang terbaik untuk peredaman energi (*steady jump*), tidak terjadi gelombang di hilir.

- Fr > 9,00

Strong jump, terjadi gelombang di hilir.

Analisis



Prinsip penurunan persamaan:

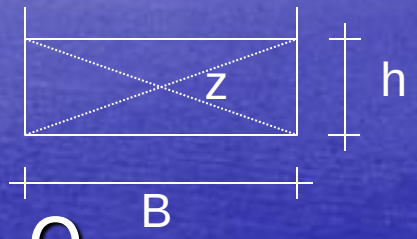
- Gaya Spesifik
- Momentum
- Energi spesifik

F1 = F2

$$\beta_1 \frac{Q_1^2}{gA_1} + Z_1 A_1 = \beta_2 \frac{Q_2^2}{gA_2} + Z_2 A_2$$

Pada saluran persegi

$$q = \frac{Q}{B}$$



Z = ½ h

$\beta_1 = \beta_2$ $Q_1 = Q_2 = Q$

$$\beta \frac{Q_1^2}{gB h_1} - \beta \frac{Q_2^2}{gBh_2} = \tfrac{1}{2} h_2 B h_2 - \tfrac{1}{2} h_1 B h_1$$

$$\beta \frac{2Q^2}{gB^2} \left(\frac{h_2 - h_1}{h_1 h_2} \right) = (h_2 + h_1)(h_2 - h_1)$$

$$h_1 h_2 (h_2 + h_1) = \beta \frac{2q^2}{g}$$

h_1 initial depth
h_2 Sequent depth

} Conjugate Depth

$$h_2 h_1^{\,2} + h_2^{\,2} h_1 - \beta \frac{2q^2}{g} = 0$$

$$h_1 h_2^{\,2} + h_1^{\,2} h_2 - \beta \frac{2q^2}{g} = 0 \quad \textit{selesaikan dengan rumus ABC}$$

$$h_2 = \frac{-h_1^2 + \sqrt{h_1^4 + \dfrac{8 h_1 \beta q^2}{g}}}{2h_1} \Rightarrow h_2 = \tfrac{1}{2} h_1 \left(\sqrt{1 + \frac{8}{h_1^3} \frac{\beta q^2}{g}} - 1 \right)$$

Konsep Energi Spesifik

h_{kr} ⟹ $\frac{\alpha \bar{U}^2}{2g} = \frac{1}{2} D$ ⟹ Fr = 1

Saluran persegi, $h_{kr} = D$; $u = q/h$

$$\frac{\alpha q^2}{g h_{kr}^2} = h_{kr} \quad \Rightarrow \quad \frac{\alpha q^2}{g} = h_{kr}^3$$

$$h_2 = \frac{1}{2} h_1 \left(\sqrt{1 + \left(\frac{2h_{kr}}{h_1} \right)^3} - 1 \right)$$

Untuk menghitung kedalaman conjugate

Jika dinyatakan dengan Fr, $Fr_1 = \frac{\overline{U}_1}{\sqrt{gh_1}} \Rightarrow Fr_1^2 = \frac{q^2}{gh_1^3}$

$$h_2 = \tfrac{1}{2} h_1 \left(\sqrt{1 + 8Fr_1^2} - 1 \right)$$

Tinggi tenaga yang hilang pada loncat air

$\Delta E = Es_1 - Es_2$

$$= (h_1 + \alpha \frac{u_1^2}{2g}) - (h_2 + \alpha \frac{u_2^2}{2g})$$

$$= h_1 - h_2 + \alpha \frac{q^2}{g} \left(\frac{1}{2h_1^2} - \frac{1}{2h_2^2} \right)$$

Untuk saluran segi empat: u=Q/A=Q/bh =q/h

$$= h_1 - h_2 + \alpha \frac{q^2}{g}\left(\frac{h_2^2 - h_1^2}{2h_1^2\, h_1^2}\right)$$

$$= h_1 - h_2 + \alpha \frac{q^2}{g}\frac{(h_1 + h_2)(h_2 - h_1)}{2h_1^2 h_2^2}$$

Dari persamaan terdahulu:

$$\frac{2\beta q^2}{g} = h_1\, h_2\, (h_2 + h_1)$$

$$\frac{\alpha\, q^2}{g} = \frac{h_1\, h_2\, (h_2 + h_1)}{2}$$

Untuk nilai $\alpha = \beta$

$$\Delta E_S = h_1 - h_2 + \frac{(h_1 + h_2)(h_2 - h_1)}{2h_1^2 h_2^2} \; \frac{h_1 h_2 (h_2 + h_1)}{2}$$

$$= h_1 - h_2 + \frac{(h_1 + h_2)(h_2^2 - h_1^2)}{4h_1 h_2}$$

$$= \frac{4h_1^2 h_2 - 4h_1 h_2^2 - h_1^3 + h_1 h_2^2 - h_1^2 h_2 + h_2^3)}{4h_1 h_2}$$

$$= \frac{h - hh + hh - h}{hh}$$

Kehilangan energi akibat loncat air untuk saluran segi empat

Panjang Loncat Air (Lj)

Dihitung berdasarkan rumus empiris

1. Woyeiski (1931)

$$\frac{Lj}{h_2 - h_1} = C - 0.05\frac{h_2}{h_1} \Rightarrow C = 8$$

2. Smetana (1933)

$$\frac{Lj}{h_2 - h_1} = C \Rightarrow C = 6$$

Lab. Mekanika Fluida UGM,
C = 4,50 - 7

3. Silvester (1964) : $\frac{Lj}{h_1} = \sigma (Fr_1 - 1)^{\Gamma}$

Saluran segi empat : σ = 9,75 ; Γ = 1,01

Saluran segi tiga : σ = 4,26 ; Γ = 0,695

Saluran trapesium dipengaruhi oleh kemiringan talud m.

m	K=b/mn	σ	Γ
2.0	16	17.6	0.905
1.0	8	23.0	0.885
0.5	4	35.0	0.836

Contoh:

1. Saluran segi empat b=3m, Q=15 m^3/det pada kedalaman 0,60 m sebelum masuk ke loncat air. Hitung kedalaman air kritis dan kedalaman air di hilir.

Solusi:

Debit aliran tiap satuan lebar

q = 15/3 = 5 m^3/det/m

Kedalaman air kritis:

$$h_{kr} = \sqrt[3]{\frac{q^2}{g}} = \sqrt[3]{\frac{5^2}{9{,}81}} = 1{,}366m$$

Kecepatan aliran:

$$v_1 = \frac{q}{h} = \frac{5}{0{,}60} = 8{,}33\ m/\det$$

Angka Froud di hulu loncat air:

$$Fr_1 = \frac{v_1}{\sqrt{gh_1}} = \frac{8{,}33}{\sqrt{9{,}81\ 0{,}6}} = 3{,}435 > 1 (aliran\ \sup\ erkritis)$$

Kedalaman air di hilir (h_2):

$$\frac{h_2}{h_1} = \tfrac{1}{2}(\sqrt{1+8Fr_1^2} - 1) = \tfrac{1}{2}(\sqrt{1+8*3{,}435^2} - 1) \Rightarrow h_2 = 2{,}63m$$

Cek:

$$Fr_2 = \frac{v_2}{\sqrt{gh_2}} = \frac{5/2{,}63}{\sqrt{9{,}81*2{,}63}} = 0{,}374 < 1\ (aliran\ subkritis)$$

2. Saluran segi empat lebar 3 m mengalirkan debit 15 m^3/det. Kemiringan dasar 0,004 dan koefisien Manning 0,01. Pada suatu titik di saluran dimana aliran mencapai kedalaman normal terjadi loncat air.

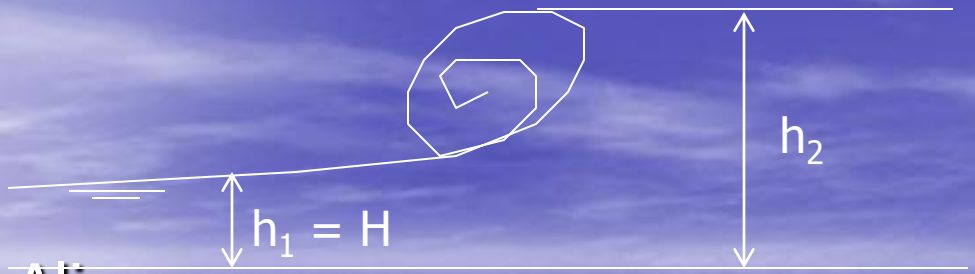
   a. tentukan tipe aliran

   b. kedalaman air setelah loncat air

   c. panjang loncat air

   d. kehilangan tenaga pada loncat air

Solusi:



a. Tipe Aliran

kedalaman air kritis: $= \sqrt[3]{\frac{q^2}{g}} = \sqrt[3]{\frac{(15/3)^2}{9{,}81}} = 1{,}366$

kedalaman air normal dihitung dengan pers. Manning:

$Q = A_1 V_1 = A_1 \frac{1}{n} R_1^{2/3} S^{1/2}$

dengan $A_1 = B h_1 = 3 h_1$ dan

$R_1 = A_1/P_1 = \frac{3h_1}{B + 2h_1} = \frac{3h_1}{3 + 2h_1}$

$$15 = 3h_1 \frac{1}{0{,}01} \left(\frac{3h_1}{3 + 2h_1} \right)^{2/3} (0{,}004)^{1/2}$$

trial, diperoleh h_1 = 1,08 m sehingga $h_1 < h_{kr}$ ..... (Superkritis)

Kecepatan Aliran

$$v_1 = \frac{Q}{A_1} = \frac{15}{3*1{,}08} = 4{,}63\ m/\det$$

$$Fr_1 = \frac{v_1}{\sqrt{gh_1}} = \frac{4{,}63}{\sqrt{9{,}81*1{,}08}} = 1{,}422 > 1$$ (aliran superkritis)

b. Kedalaman setelah loncat air

$$h_2 = \tfrac{1}{2} h_1 (\sqrt{1+8Fr_1^2} - 1) = \tfrac{1}{2} * 1{,}08 (\sqrt{1+8*1{,}42^2} - 1) \Rightarrow h_2 = 1{,}70\ m$$

Cek:

$$Fr_2 = \frac{v_2}{\sqrt{gh_2}} = \frac{(15/3*1{,}7)}{\sqrt{9{,}81*1{,}70}} = 0{,}72 < 1 (aliran\ \ subkritis)$$

c. Panjang Loncat Air

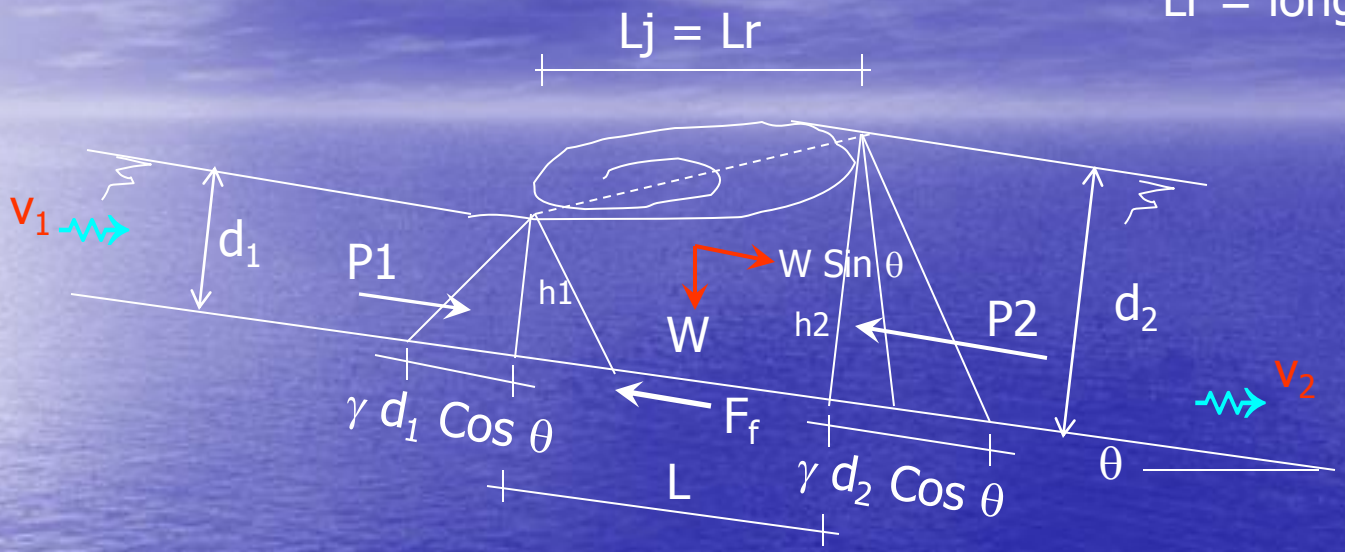
$Lj = 6\,(h_2 - h_1) = 6\,(1{,}7 - 1{,}08) = 3{,}72$ m

d. Kehilangan Tenaga

$$\Delta E_S = \frac{(h_2 - h_1)^3}{4h_1h_2} = \frac{(1{,}7 - 1{,}08)^3}{4 * 1{,}08 * 1{,}7} = 0{,}032\,m$$

LONCAT AIR PADA SALURAN MIRING

Lr = long of roller



Dipandang lebar 1 satuan $\perp$ bidang gambar

Persamaan Momentum:

$$\rho q(v_2 - v_1) = P_1 - P_2 + W \sin\theta - F_f$$

Persamaan Kontinuitas:

$$q = v_1 d_1 = v_2 d_2 \Rightarrow v_2 = \frac{v_1 d_1}{d_2}$$

$F_f \approx 0$

$$P_1 = \tfrac{1}{2}\gamma d_1^2 Cos\theta \; dan \; P_2 = \tfrac{1}{2}\gamma d_2^2 Cos\theta$$

Luas distribusi tekanan hidrostatis

Dengan menganggap profil loncat air adalah garis lurus, berat loncat air adalah:

$$W = \tfrac{1}{2}\gamma Lj \, Cos\theta (d_2 + d_1)$$

Profil muka air sebenarnya tidak lurus, maka perlu dikoreksi:

$$W = \tfrac{1}{2}\gamma K\, Lj\, Cos\,\theta (d_2 + d_1)$$

$$\frac{\gamma}{g} v_1 d_1 \left(\frac{v_1 d_1}{d_2} - v_1 \right) = \tfrac{1}{2}\gamma K\, Lj (d_2 + d_1) Sin\,\theta + \tfrac{1}{2}\gamma d_1^2 Cos\,\theta - \tfrac{1}{2}\gamma d_2^2 Cos\,\theta$$

$$\left(\frac{d_2}{d_1} \right)^3 - (2G^2 + 1)\frac{d_2}{d_1} + 2G^2 = 0$$

$$dengan\, G = \frac{Fr_1}{\sqrt{Cos\,\theta - \dfrac{K\, Lj\, Sin\,\theta}{(d_2 - d_1)}}}$$

Penyelesaiannya:

$$\frac{d_2}{d_1} = \frac{1}{2}\left(\sqrt{1+8G_1^2} - 1\right) \Rightarrow d_2 = h_2 \, Cos\,\theta;\; d_1 = h_1 \, Cos\,\theta$$

$$\frac{h_2}{h_1} = \frac{1}{2}\left(\sqrt{1 + 8G_1^2} - 1\right)$$

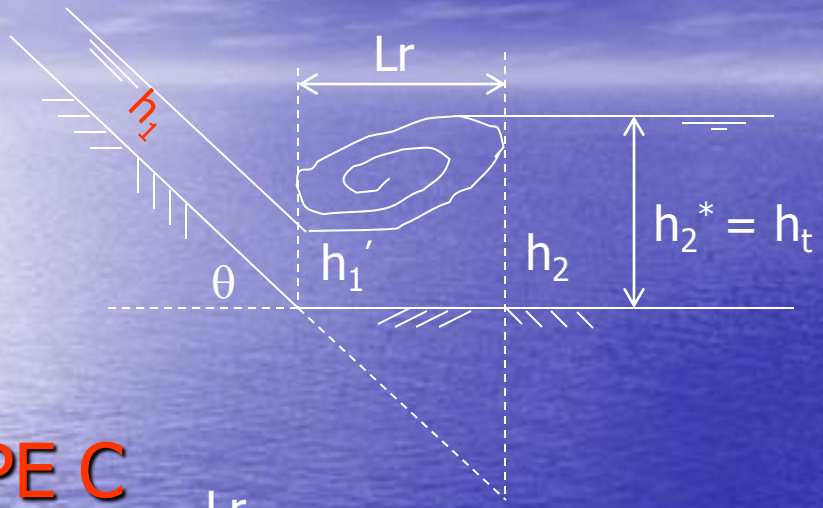
Rajaratnam: $G_1 = K_1^2 \, Fr_1^2$

$K_1 = 10^{0,027\theta}$ dengan θ dalam derajat

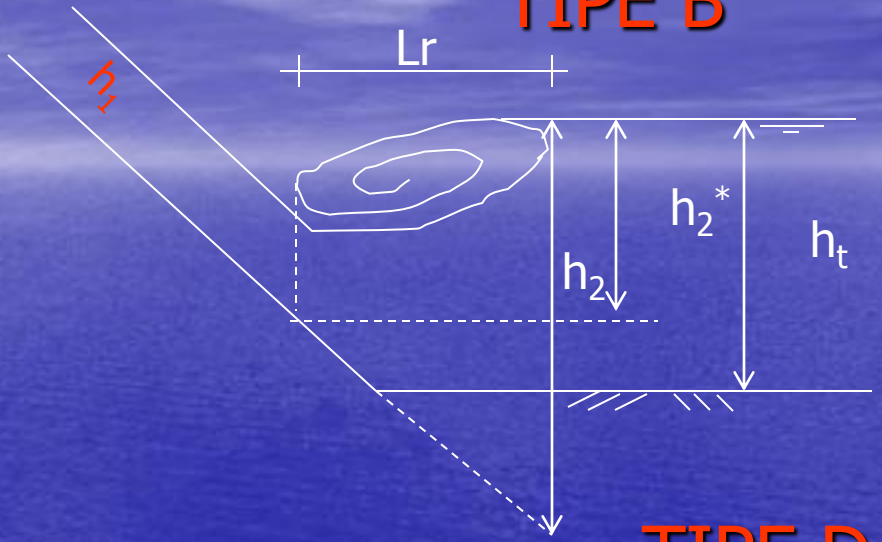
$$K_1 = \frac{1}{\sqrt{Cos\,\theta - \dfrac{K\,Lj\,Sin\,\theta}{d_2 - d_1}}}$$

TIPE-TIPE LONCAT AIR

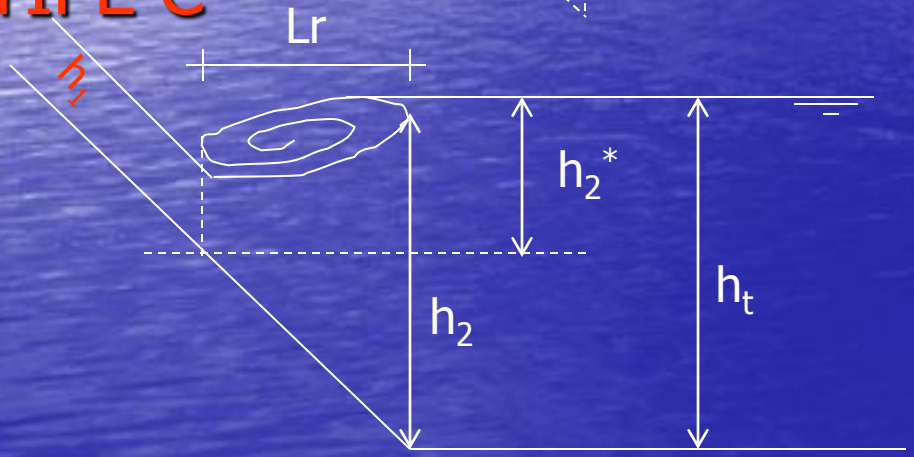
TIPE A



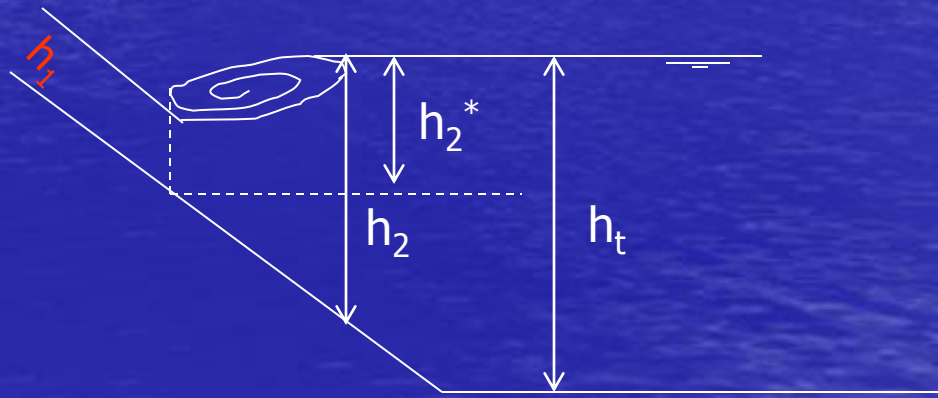
TIPE B



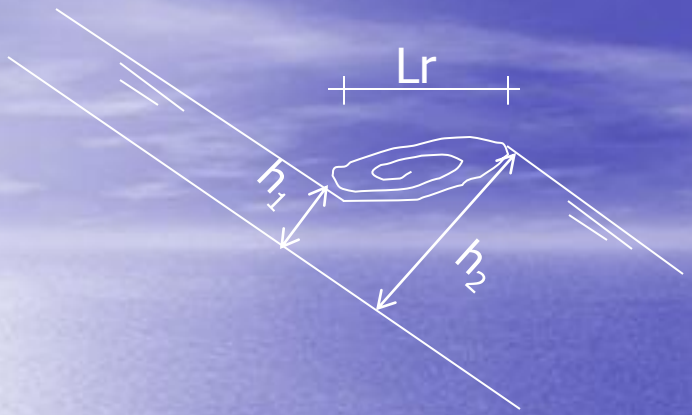
TIPE C



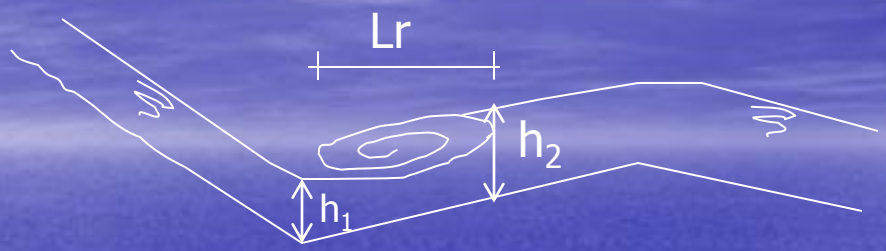
TIPE D



TIPE E



TIPE F



Lr = panjang loncat air horizontal

h_1 = kedalaman air di hulu

h_t = kedalaman air di hilir (*tail water depth*)

h_2^* = kedalaman air subkritik yg diberikan dgn rumus loncat air pd saluran horizontal

h_2 = kedalaman air subkritik yg diberikan dgn rumus loncat air untuk saluran miring

Rumus yang digunakan sama dengan saluran horizontal

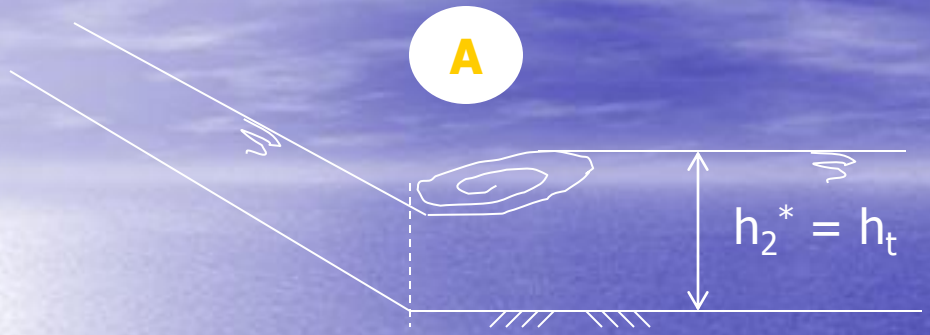
$$\frac{h_2}{h_1} = \frac{1}{2}\left(\sqrt{1+8G_1^2} - 1\right)$$

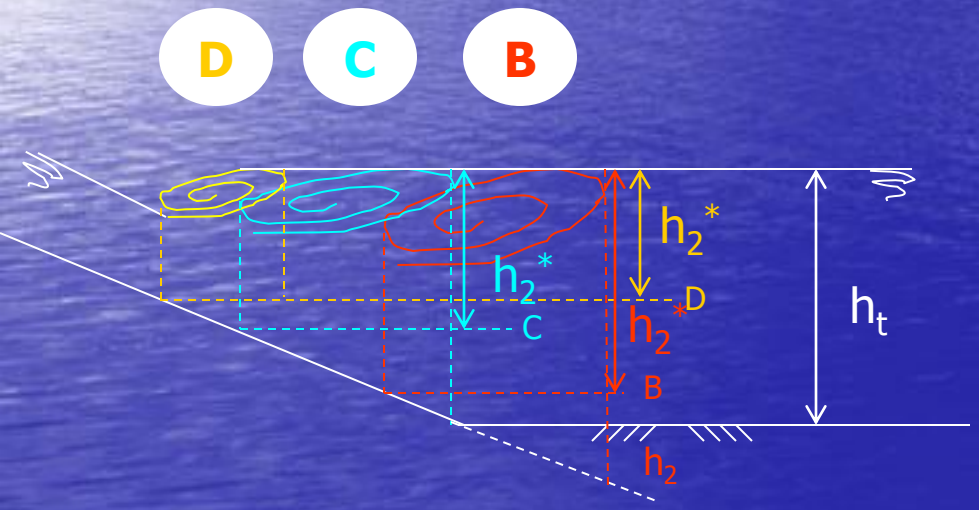
$$G_1^2 = K_1^2\, Fr_1^2; \quad K_1 = 10^{0,027\theta} \quad jika\ \theta \approx 0 \Rightarrow K_1 = 1 \Rightarrow G_1^2 = Fr_1^2$$

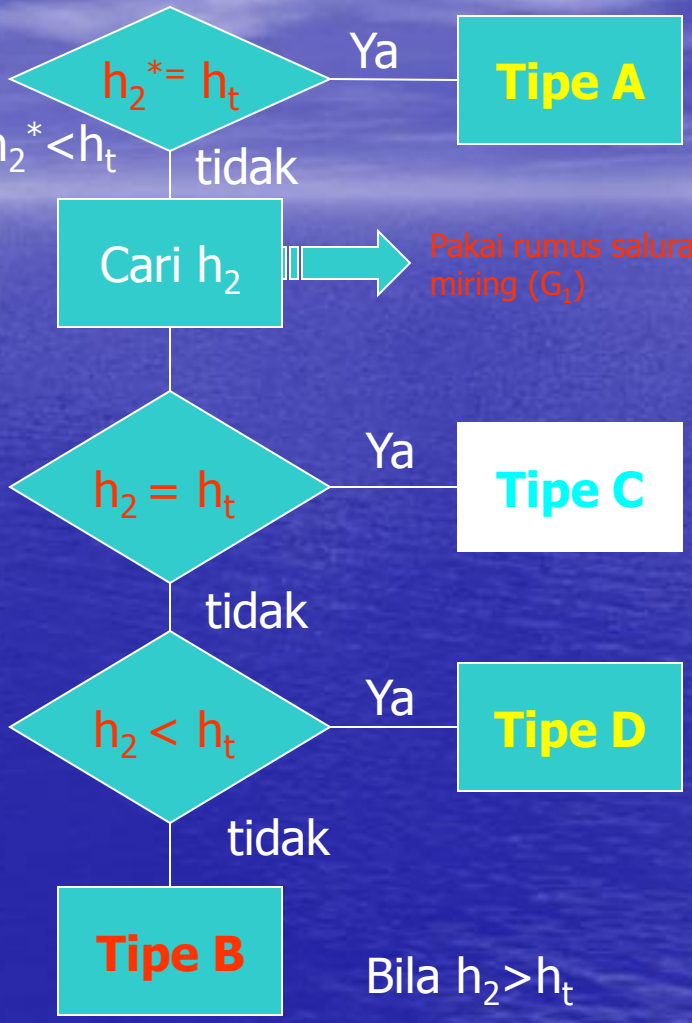
$$h_1' = \frac{h}{Cos\,\theta}$$

$$\frac{h_2^*}{h_1} = \frac{1}{2}\left(\sqrt{1+8Fr_1^2} - 1\right)$$

PROSEDUR PERHITUNGAN LONCAT AIR







Contoh

Saluran segi empat, lebar 1,20 m dan miring thd horizontal 3º. Tentukan tipe loncat air jika Q=0,14 m^3/det; h_1=0,018 m dan h_t=0,40 m.

Solusi:

$A_1 = b_1 h_1 = 1{,}20 * 0{,}018 = 0{,}022\ m^2$

$u_1 = Q/A_1 = 0{,}14/0{,}022 = 6{,}36$ m/det

$$Fr_1 = \frac{u_1}{\sqrt{gh_1}} = \frac{6{,}36}{\sqrt{9{,}81*0{,}018}} = 15{,}14 > 1 \Rightarrow \text{superkriti k}$$

Kedalaman air konjugasi h_2^* (rumus sal. Horizontal)

$$h_2^* = \frac{h_1'}{2}\left(\sqrt{1+8Fr_1^2} - 1\right) = \frac{h_1}{2Cos\theta}\left(\sqrt{1+8Fr_1^2} - 1\right)$$

$$h_2^* = \frac{0{,}018}{2Cos\,3}\left(\sqrt{1+8*15{,}14^2} - 1\right) = 0{,}377m$$

Karena $h_t > h_2^*$ ⟹ bukan loncat air tipe A

Dicari nilai h_2:

$$h_2 = \frac{h_1}{2Cos\theta}\left(\sqrt{1+8G_1^2}\ -1\right) \Rightarrow G_1^2 = K_1^2\, Fr_1^2 \; dan \; K_1 = 10^{0,027\theta}$$

$$K_1 = 10^{0,027\theta} = 10^{0,027*3} = 1,20; G_1^2 = 1,20^2 * 15,14^2 = 324$$

$$h_2 = \frac{0,018}{2Cos\,3}\left(\sqrt{1+8*324}\ -1\right) = 0,45\,m$$

$h_2 > h_t$ ⟹ loncat air tipe B

Dari grafik (panjang loncat air)

$$\frac{h_t}{h_2^*} = \frac{0,4}{0,377} = 1,06\,m \Rightarrow \frac{\ell}{h_2^*} = 4 \Rightarrow \ell = 1,51\,m$$

$$Fr_1 = 15,14 \Rightarrow \frac{Lj}{h_t} = 4,90 \Rightarrow Lj = 4,90 * 0,40 = 1,96\,m$$

Kehilangan Energi

$$E_1 = \ell \tan\theta + \frac{h_1}{Cos\,\theta} + \frac{u_1^2}{2g} = 1{,}51 \tan 3^0 + \frac{0{,}018}{Cos\,3} + \frac{6{,}36^2}{2*9{,}81} = 2{,}16\,m$$

$$E_2 = h_t + \frac{u_2^2}{2g} = 0{,}40 + \frac{[0{,}14/(1{,}20*0{,}40)]^2}{2*9{,}81} = 0{,}404\,m$$

$$\Delta E = E_1 - E_2 = 2{,}16 - 0{,}404 = 1{,}756\,m$$

$$\frac{\Delta E}{E_1} = \frac{1{,}756}{2{,}66}\ X\,100\% = 81\%$$

Contoh lagi:

Saluran segi empat b=6,10 m kemiringan saluran thd horizontal 3^o, tentukan tipe loncat air jika Q=9,0 m^3/det, h_t=2,60 m dan h_1=0,09m.

Solusi:

$A_1 = b\ h_1 = 6{,}1 * 0{,}09 = 0{,}55\ m^2$

$U_1 = Q/A_1 = 9/0{,}55 = 16\ m/det$

$$Fr_1 = \frac{u_1}{\sqrt{g h_1}} = \frac{16}{\sqrt{9{,}81 * 0{,}09}} = 17$$

$$h_2^* = \frac{h_1'}{2}\left(\sqrt{1 + 8Fr_1^2} - 1\right) = \frac{0{,}09}{2}\left(\sqrt{1 + 8 * 17^2} - 1\right) = 2{,}1m$$

$h_t > h_2^*$ ⟹ bukan loncat air type A , hitung h_2

$$K_1 = 10^{0{,}027\theta} = 10^{0{,}027*3} = 1{,}20; G_1^2 = 1{,}20^2 * 17^2 = 416$$

$$h_2 = \frac{0,09}{2\,Cos\,3}\left(\sqrt{1+8*416^2}\ -1\right) = 2,60\,m$$

h_2 y h_t ⇒ Loncat Air Tipe C

$Fr_1 = 17$

$\text{Tan}\ \theta = 0,05$

$$\left.\begin{array}{l} \\ \\ \end{array}\right\} \frac{Lj}{h_t} = 4,8 \Rightarrow Lj = 4,8*2,6 = 12\,m$$

$$E_1 = Lr\tan\theta + \frac{h_1}{\cos\theta} + \frac{u_1^2}{2g} = 12\tan 3^o + \frac{0,09}{\cos 3^o} + \frac{16^2}{2*9,81} = 13,77\,m$$

$$E_2 = h_2 + \frac{u_2^2}{2g} = 2,6 + \frac{(9/6,1*2,6)^2}{2*9,81} = 2,616\,m$$

$$\Delta E = \frac{E_1 - E_2}{E_1} = \frac{13,77 - 2,616}{13,77}\ X\,100\% = 81\%$$

UJIAN TENGAH SEMESTER

- Annotation (melaporkan hasil bacaan), hunting di internet minimal dua judul makalah/jurnal hidraulika
- Cantumkan alamat website dan tanggal akses
- Waktu 48 jam
- Makalah/jurnal dilampirkan pada annotation

See you next week !