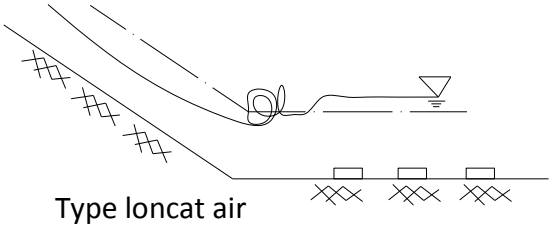
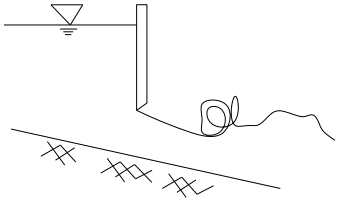
LONCAT AIR (Hydraulics Jump)

- Terjadi apabila suatu aliran superkritis berubah menjadi aliran subkritis terjadi pembuanagn enrgi
- Konsep hitungan loncat air sering dipakai pada perhitungan bangunan peredam energy
  a. Disebelah hilir bangunan pelimpah
  b. Disebelah hilir pintu air



Type loncat air



"Undular jump"

"Oscilating Jump"

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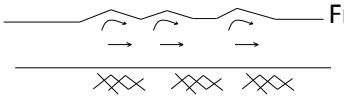
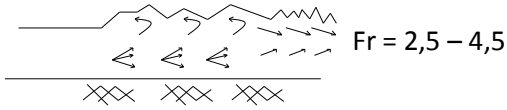
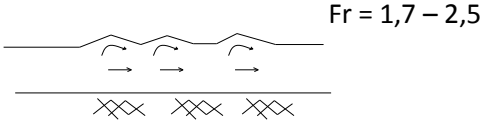
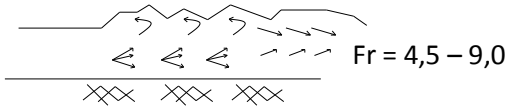




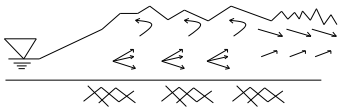
"Weak Jump"

"Steady Jump"





"Strong Jump"



Fr = > 9,0

- Fr : 1 – 1,7

  Perubahan aliran superkritis menjadi subkritis terjadi secara tiba – tiba → terlihat deretan gelomabang beromabak dipermukaan air (undular jump)

- Fr : 1,7 – 2,5

  Gelomabang pada permukaan (loncat air) mulai pecah → loncat air masih lemah (weak jump)

- Fr : 2,5 – 4,5

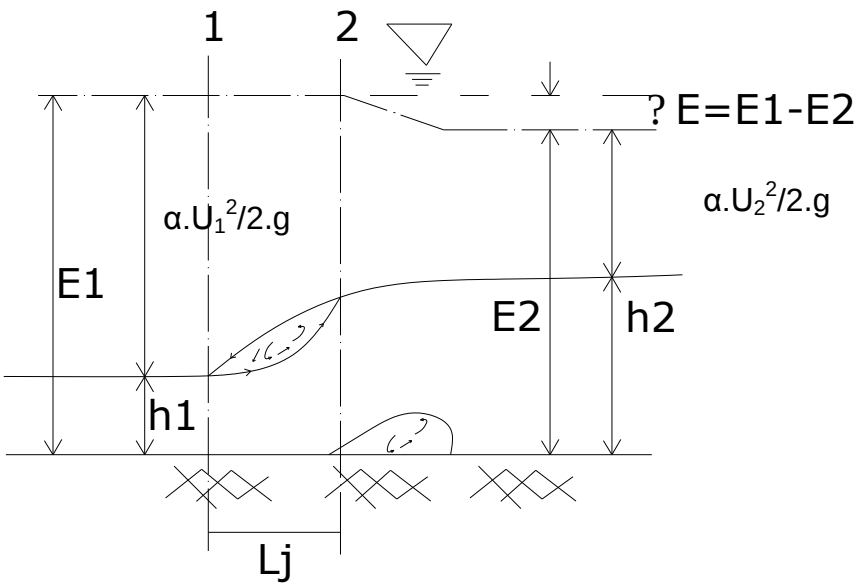
  Terjadi osilasi (oscillating jump) → loncat air dengan gelombang dibelakangnya

- Fr : 4,5 – 9,0

  Loncatan yang terbaik untuk peredam energy (steady jump) → tidak terjadi gelombang di hilir

- Fr > 9,0

  Strong jump, terjadi gelomabang di hilir



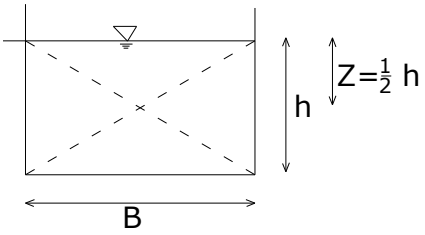
Prinsip penurunan persamaan:

- Gaya spesifik
- Momentum
- Energy spesifik)

$F_1 = F_2$

$B_1.(Q_1^2)/g.A_1 + Z_1.A_1 = B_2.(Q_2^2)/g.A_2 + Z_2.A_2$

Pada saluran persegi



$Q = Q/A$

$A = B.h$

$\beta 1 \approx \beta 2$

$Q1 = Q2 = Q$

$\beta.(Q_1^2/g.B.h_1) - \beta.(Q_2^2/g.B.h_2) = 1/2h2.\beta h2 - 1/2h1.\beta h1$

$\beta.(2Q^2/g.B^2)\ ((h2-h1)/(h1.h2)) = (h2+h1).(h2-h1)$

$h1.h2.(h2+h1) = (\beta.2q^2)/g$

h1 dan h2 → Sequwnt depth (h2)

initial depth (h1)

conjugate depth

$h_2.h1^2 + h2^2.h_1 - (2\beta.q^2)/g = 0$

$h_2.h1^2 + h2^2.h_1 - (2\beta.q^2)/g = 0$ → rumus abc: $ax^2 + bx + c = 0$

$h_2 = (-h1^2 + \sqrt{h1^4 + 8h1.\ \beta.q^2)/g})/(2h1)$

$h2 = ½\ h1\ (\sqrt{1 + (8h1^3.\ \beta.q^2)/g})) - 1$

konsep energy spesifik

$hkr \rightarrow \alpha.U^2/2.g = D/2 \rightarrow Fr = 1$

saluran persegi → hkr = D:U=q/h

$\alpha.q^2/(g.h^2kr) = hkr \rightarrow \alpha q^2/g = hkr^3$

$\alpha \sim \beta \rightarrow \beta.q^2)/g = hkr^3$

$h2 = ½\ h1\ (\sqrt{1 + (2hkr/h1)^3} - 1$ → untuk menghitung kedalaman conjugate

dengaFr : $Fr1 = (U1/\sqrt{gh1}) \rightarrow Fri^2 = q^2/gh1^3$, $\beta \approx 1$

$h2 = ½\ h1.(\sqrt{1+8Fr1^2} - 1)$

tinggi tenaga yang hilang pada loncat air

$\Delta Es = Es1 – Es2$

$= (h1 + (\alpha.U1^2/2g) - (h2 + (\alpha.U2^2/2g)$ → untuk saluran segi empat

$= h1 –h2 + (\alpha.q^2/g).(1/2h1^2 - 1/2h2^2)$

$= h1 –h2 + (\alpha.q^2/g).(h2^2 – h1^2/2h1^2.h2^2)$

$= h1 –h2 + (h1+h2)(h2-h1)/(2h1^2.h2^2).(\alpha.q^2/g)$

Dari persamaan terdahulu :

$2\beta.q^2/g = h_1h_2.(h_1 + h_2)$ untuk nilai $\alpha = \beta$

$\alpha.q^2/g = h_1h_2.(h_1 + h_2)$

$\Delta Es = h_1 - h_2.((h_1 + h_2). (h_1 - h_2)/2(h_1^2 h_2^2)). ((h_1 h_2).(h_1+h_2)/2))$

$= h_1 - h_2.((h_1 + h_2). (h_1 - h_2)/4(h_1h_2)).$

$= (4 h_1^2h_2 - 4 h_1 h_2^2 - h_1^3 + h_1 h_2^2 - h_1^2h_2 + h_2^3)/ 4(h_1h_2)$

$\Delta Es =(h_2 – h_1)^3/ (4h_1.h_2)$ → kehilangan energy akibat loncat air (untuk saluran segi empat)

- Panajang Loncat Air (Lj)
  - Dihitung berdasarkan rumus empiris

1. Woyeiski (1931)

   $(Lj)/(h_1 - h_2) = C – 0,05 (h_2/h_1)$; C = 8

2. Smetana (1933) : $(Lj)/(h_2 - h_1) = C$; C= 6

   Labotorium mekanika fluida UGM ; C = 4,5 – 7

3. Silvester (1964)

   $(Lj/ h_1) = \sigma (Fri – 1)^{\Pi}$

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

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

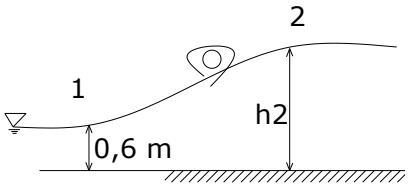
- Saluran trapezium dipengaruhi oleh kemiringan talud m

m	k□=(b/m.h)	σ	Π
2,0	16	17,6	0,905
1,0	8	23,0	0,885
0,5	4	35,0	0,836

Contoh

1. Salurqan segi empat b = 3m; Q = 15m^3/detik pada kedalaman 0,6 m sebelum masuk ke loncat air. Hitung kedalaman air kritis dan kedalaman air di hilir

   Solusi



- Debit aliran tiap saluran lebar

  Q = 15/3 = 5 m^3/d/m

- Kedalaman air kritis

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

  Kecepatan aliran

  V_1 = q/h_1 = 5/0,6 = 8,33 m/d

  Angka Froud di hulu loncat air (1)

  Fri = V_1/ √g.h1 = 8,33/ √9,81.0,6 = 3,435 > 1 superkritis

  Kedalaman air di hilir (h_2)

  h2/h1 = ½ (√1 + 8$Fr1^2$ – 1) = ½ (√ 1 + 8.3,435^2 – 1)

  h2 = 2,63 m

  Cek : Fr_2 = U_2/√g.h2 → U_2=g/h2 = 5/2,63 = 1,901

  = 1,901 /√9,81.2,63 = 0,374 < 1 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

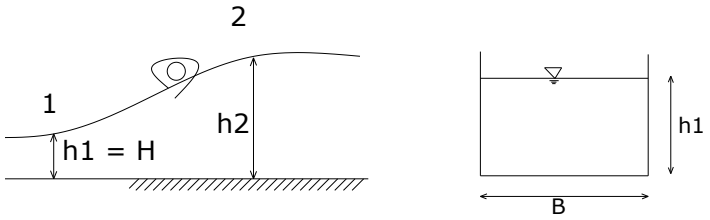
   a. Tentukan tipe aliran

   b. Kedalaman air sebelah loncat air

   c. Panjang loncat air

   d. Kehilangan tenaga pada loncat air

Solusi



a. Tipe aliran

   Kedalaman air kritis

   $Hkr = \sqrt[3]{q^2/g} = \sqrt[3]{(15/3)^2/9,81} = 1,366$ m

   Kedalaman air normal dihitung dengan rumus Manning : $Q = A_1.V_1 = A_1(1/n).R_1^{2/3}.S^{1/2}$

   Dengan, $A_1 = B.h_1 = 3.h_1$

   $R_1 = A_1/P_1 = 3h_1/(B+2h_1) = 3h_1/(3+2h_1)$

   $15 = 3h_1.(1/0,01).(3h_1/(3+2h_1))^{2/3}.(0,004)^{1/2}$

   $0,791 = h_1.(3h_1/(3+2h_1))^{2/3}$ ➔, $h_1 = 1,08$ m

   h_1 = hkr (superkritis)

   kecepatan aliran

   $V_1 = Q/A_1 = 15/(3.1,08) = 4,63$ m/d

   $Fr_1 = V_1/\sqrt{g.h_1} = 4,63/\sqrt{9,81.1,08} = 1,422$ (aliran superkritis)

   Oleh karena $Fr_1 > 1$, maka aliran superkritis

b. Kedalaman setelah loncat air (h_2)

$h_2 = h_1/2.(\sqrt{1 + 8Fr_1^2} - 1) = 1{,}08/2.(\sqrt{1 + 8.(1{,}42^2)} - 1)$

$h_2 = 1{,}70$ m

cek : $Fr_2 = V_2/\sqrt{g.h_2} \rightarrow V_2 = g/h_2 = 15/3.\ 1{,}7 = 2{,}941$ m/det

$= 2{,}941/\ \sqrt{9{,}81.1{,}7} = 0{,}72 < 1$ (aliran subkritis)

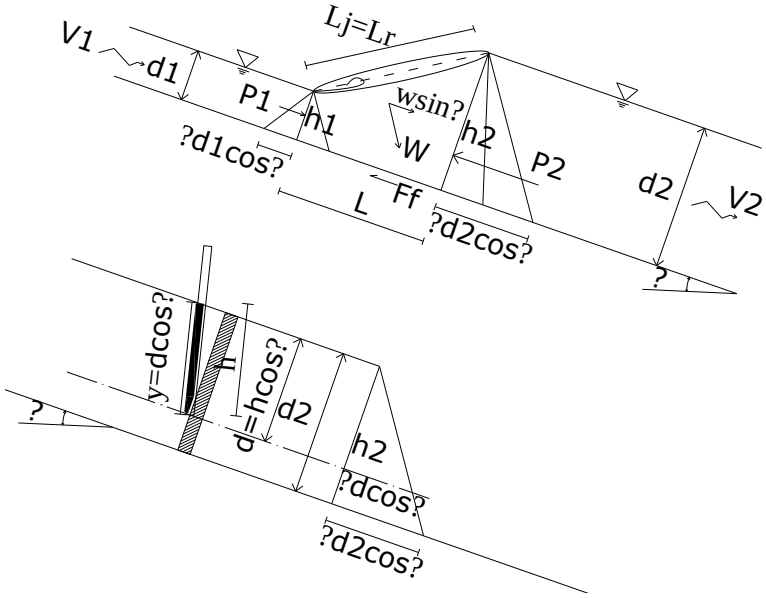
c. Panjang loncat air

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

d. Kehilangan tenaga

$\Delta Es = (h_1 - h_2)^3 / 4.h_1.h_2 = (1{,}7 - 1{,}08)^3 / 4.1{,}08.1{,}7 = 0{,}032$ m

Loncat Air Pada Saluran Miring



Dipandang lebar 1 satuan $\perp$ bidang gambar. Persamaan momentum

$P.q.(V_2 - V_1) = P_1 - P_2 + w \sin \theta - Ff$

Persamaan kontinuitas

$Q = V_1.d_1 = V_2.d_2 \rightarrow V_2 = (V_1.d_1)/d_2$

$Ff \approx 0$

$P_1 = ½ \gamma.d_1^2.\cos\theta$ → luas distrik tekanan hidrostatis

$P_2 = ½ \gamma.d_2^2.\cos\theta$

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

$W = ½ \gamma.Lj.\cos\theta.(d_1+d_2)$

Profil muka air sebenarnya tidak lurus, maka perlu dikoreksi:

$W = ½ \gamma.K.\ Lj.\cos\theta.(d_1+d_2)$

$\gamma/g\ .\ V_1.d_1.\ ((V_1.d_1)/d_2 - V_1) = ½ \gamma.d_1^2.\cos\theta - ½ \gamma.d_2^2.\cos\theta + ½ \gamma.K.\ Lj..(d_1+d_2).\ \sin\theta$

$(d_2/d_1)^3 - (2G^2 + 1)\ (d_2/d_1) + 2G^2 = 0$

Dengan $G = Fr_1/(\sqrt{\cos\theta} - (K.\ Ljsin\ \theta)/(d_1-d_2))$

Penyelesaiannya:

$(d_2/d_1) = ½ (\sqrt{1 + 8G_1^2} - 1)$

$d_2 = h_2\ \cos\theta$; $d_1 = h_1\ \cos\theta$

$(h_2/h_1) = ½ (\sqrt{1 + 8G_1^2} - 1)$

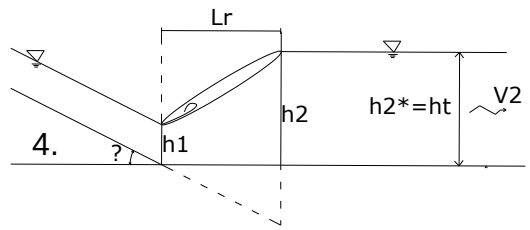
Rjaratnam : $G_1^2 = K_1^2.\ Fr_1^2$

$K_1 = 10^{0,0278\ \theta}$ → dimana: θ = derajat

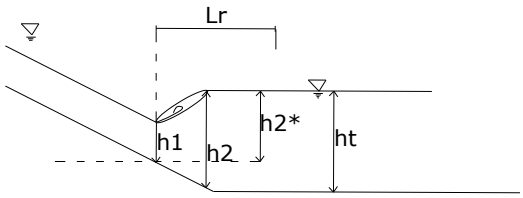
$K_1 = 1/(\sqrt{\cos\theta} - (K.\ Ljsin\ \theta)/(d_1-d_2))$

Tipe – tipe loncat air

TYPE A



TYPE D



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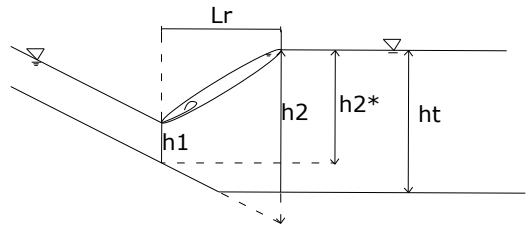
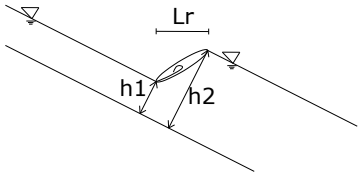


TYPE E



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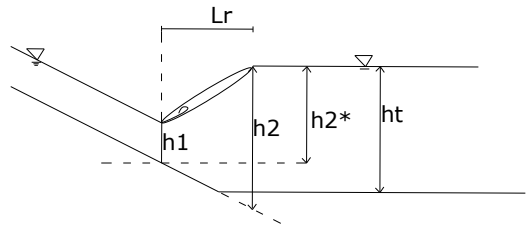

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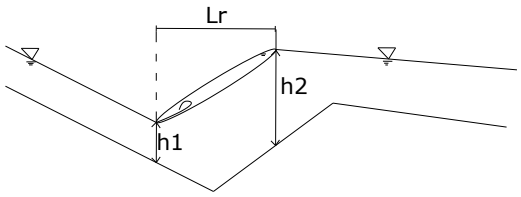


Lr = panjang loncat air horizontal

h_1 = kedalaman air di hulu

ht = kedalaman air di hilir (tail water depth)

h_2* = kedalaman air subkritik yang diberikan dengan rumus loncat air pada saluran horizontal

h_2 = kedalaman air subkritik yang diberikan dengan rumus loncat air untuk saluran miring

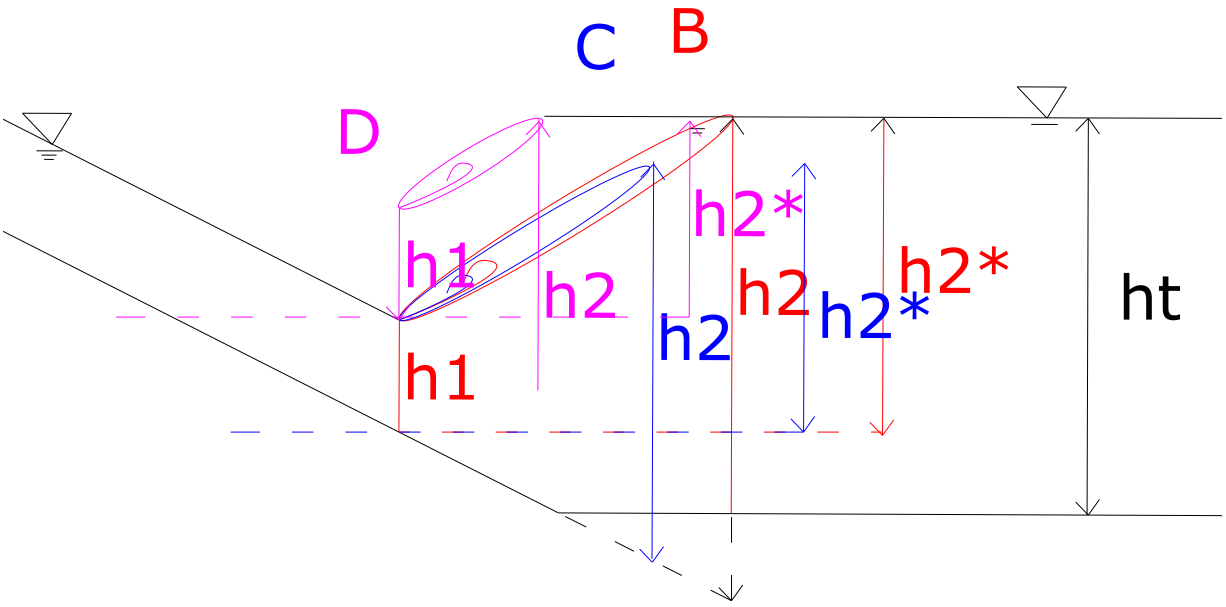
rumus yang digunakan sama dengan saluran horizontal

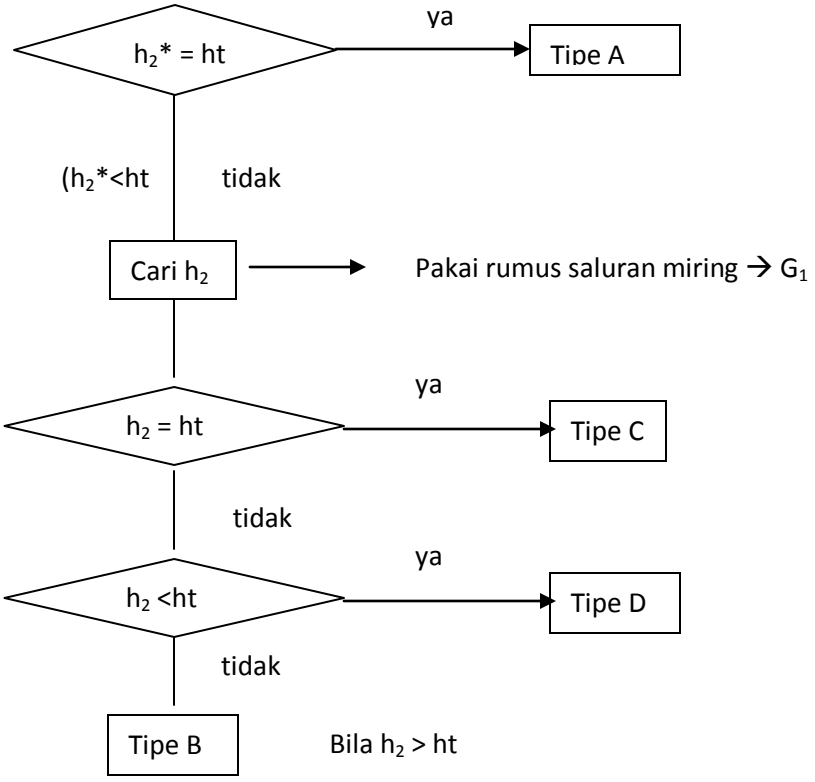
$(h_2/h_1) = ½ (\sqrt{1 + 8G_1^2} - 1)$

$G_1^2 = K_1^2 . Fr_1^2$

$K_1 = 10^{0,0278\ \theta}$ → jika $\theta = 0$ → $K_1 = 1$ → $G_1^2 = Fr_1^2$

$(h_2^*/h_1) = ½ (\sqrt{1 + 8Fr_1^2} - 1)$





Contoh

Saluran segiempat, lebar b = 1,2 m dan miring terhadap horizontal 3^0. Tentukan tipe loncat air jika Q = 0,14 m^3/s ; h_1 = 0,018m ; ht = 0,40 m

Solusi

$A_1 = b.h_1 = 1,2 \times 0,018 = 0,022\ m^2$

$U_1 = Q/A_1 = 0,14/0,022 = 6,36$ m/s

$Fr_1 = U_1/\sqrt{g.h_1} = 6,36/\sqrt{9,81.0,018} = 15,14 > 1 \rightarrow$ super kritik

Kedalaman air konjugasi h_2^* →rumus saluran horizontal

$h_2^* = h_1^*/2. (\sqrt{1 + 8Fr_1^2} - 1) \rightarrow h_1^* = h_1/\cos\theta$

$= h_1/2.\cos\theta . (\sqrt{1 + 8Fr_1^2} - 1) = (0,018/2 \cos 3^0).(\sqrt{1 + 8.15,14^2} - 1) = 0,377$ m

Karena ht > h_2^* → bukan loncat air tipe A

Dicari nilai h_2

$h_2 = h_1^*/2. (\sqrt{1 + 8G_1^2} - 1) \rightarrow G_1^2 = K_1^2. Fr_1^2$

$K_1 = 10^{0,027\,\theta} \rightarrow 10^{0,027.\,3}$

$= 1,2$

$G_1^2 = 1,2^2. 15,14^2$

$= 324$

$h_2 = ½ (0,018/\cos 3^0).(\sqrt{1 + 8.324^2} - 1) = 0,45$

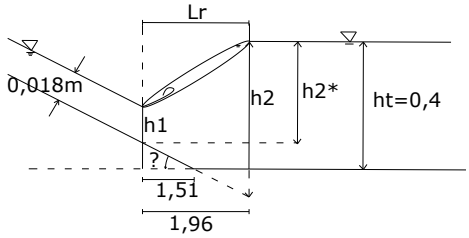
$h_2 >$ ht → loncat air tipe B

dari garfik (panjang loncat air)

$ht/h_2^* = 0,4/0,377 = 1,06 \rightarrow l/ h_2^* = 4 \rightarrow l = 1,51$ m

$Fr_1 = 15,14 \rightarrow Lj/ht = 4,9 \rightarrow 4,9 . 0,4 = 1,96$ m

TYPE B



Kehilangan energy

$E_1 = l \tan \theta + (h_1/\cos\theta) + (U_1^2/2g)$

$= 1{,}51 \tan 3^0 + (0{,}018/\cos 3^0) + (6{,}36^2/2.9{,}81) = 2{,}16$ m

$E^2 = ht + (U_2^2/2g) = 0{,}4 + (0{,}14/(1{,}2.0{,}4))^2/2.9{,}81 = 0{,}404$ m

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

$\Delta E/ E_1 = 1{,}756/2{,}16 \times 100\% = 81\%$

Contoh 2

Saluran segiempat b = 6,1m kemiringan saluran terhadap horizontal 3^0, tentukan tipe loncat air jika Q =9,0 m^3/s, ht = 2,6 m dan $h_1 = 0{,}09$ m

Solusi

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

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

$Fr_1 = U_1/\sqrt{g.h_1} = 16/\sqrt{9{,}81} . 0{,}09 = 17$

$h_2^* = h_1^*/2. (\sqrt{1 + 8Fr_1^2} - 1) = 0{,}09/2 . (\sqrt{1 + 8.17^2} - 1) = 2{,}1$ m

$ht > h_2^* \rightarrow$ bukan loncat air tipe A $\rightarrow$ hitung h_2

$K_1 = 10^{0{,}027\,\theta} \rightarrow 10^{0{,}027.\,3}$

$= 1{,}2$

$G_1^2 = 1{,}2^2 . 17^2$

$= 416$

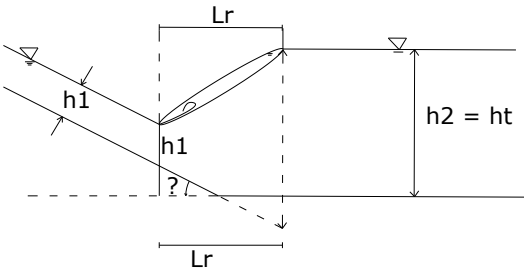
$h_2 = h_1/2 \cos\theta . (\sqrt{1 + 8G_1^2} - 1) = 0{,}09/2.\cos 3^0 . (\sqrt{1 + 8.416^2} - 1) = 2{,}6$ m

$h_2 \approx ht \rightarrow$ loncat air tipe C

Fr1 = 17

Tanθ = 0,05

Maka Lj/ht = 4,8 → Lj = 4,8 . 2,6 = 12 m



$E_1 = Lr\ tg\theta + (h_1/cos\theta) + (U_1^2/2g) = 12\ tg\ 3^0 + (0,09/cos\ 3^0)+(16^2/2.9,81) = 13,77m$

$E_2 = h_2+(U_2^2/2g) = 2,6\ ((9/6,1.2,6)^2/(2.9,81)) = 2,616\ m$

$\Delta E = (E_1 – E_2)\ /E_1 = (13,77 – 2,616)/13,77\ x\ 100\% = 81\%$