Irrigation and Drainage Engineering

(Soil Water Regime Management)

(ENV-549, A.Y. 2025-26)

4ETCS, Master option

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Platform of Hydraulic Constructions

Lecture 3-1. Surface irrigation: hydraulic design of canals

Review of free-surface flow and hydraulic design of canals

Flow classification

Type of flow

- **permanent** $\frac{\partial}{\partial t} = 0$
  - **uniform** $\frac{\partial}{\partial x} = 0$
  - **varied**
    - **gradually**
    - **suddenly**
- **transient** $\frac{\partial Q}{\partial x} + \frac{\partial A}{\partial t} = 0$

x : longitudinal coordinate
Q : flow discharge
A : flow area

Flow regime (Reynolds number *Re*)

- **laminar** $Re < 500$
- **turbulent** $Re > 2000$

$$Re = \frac{U\,R}{\nu}$$

U : mean flow velocity
R : hydraulic radius
ν : kinematic viscosity = ν (Temperature)

$\nu \propto 10^{-6}\ \mathrm{m^2/s}$

Flow kinematics (Froude number *Fr*[1])

- **fluvial** $Fr < 1$ **($y > y_c$)**
- **critical** $Fr = 1$ **($y = y_c$)**
- **torrential**[2] $Fr > 1$ **($Y < y_c$)**

$$Fr = \frac{U}{\sqrt{g\,y}}$$

y : water depth
y_c : critical water depth

[1] Compare the kinetic energy and the potential energy of the water flow
[2] Waves can't propagate upstream

Flow regime – Reynolds number

Characterises the relative importance of the forces of inertia and viscosity:

$$Re = U\,L\,/\,\nu$$

(U: mean flow velocity; L: characteristic dimension, ν: kinematic viscosity of water)

Channel flow :

$$Re = U\,R\,/\,\nu$$

(R : hydraulic radius)

- Laminar flow regime: viscosity forces predominate over inertia forces (Re < 500)
- Turbulent flow regime: the forces of viscosity are of little importance compared with the forces of inertia (Re > 500)[1]. Velocities fluctuate randomly around mean values. This is the type of flow generally encountered.

1 Some authors introduce a transition regime for 500 < Re < 2000 and therefore place the lower limit of the turbulent regime at 2000.

For pressure flow in circular pipes of diameter D: R = D/4, so that the limit between laminar and turbulent flow is no longer 500, but 2000.

Uniform free-surface flow

Total hydraulic energy per unit weight of water: $H = z + \frac{p}{\rho_w g} + \frac{U^2}{2g} = z + y + \frac{U^2}{2g}$

Flow conditions= f {
- flowrate
- channel characteristics (slope, roughness, geometry, etc.)

$\frac{dH}{dx} = -S$ Loss of energy, positive downstream

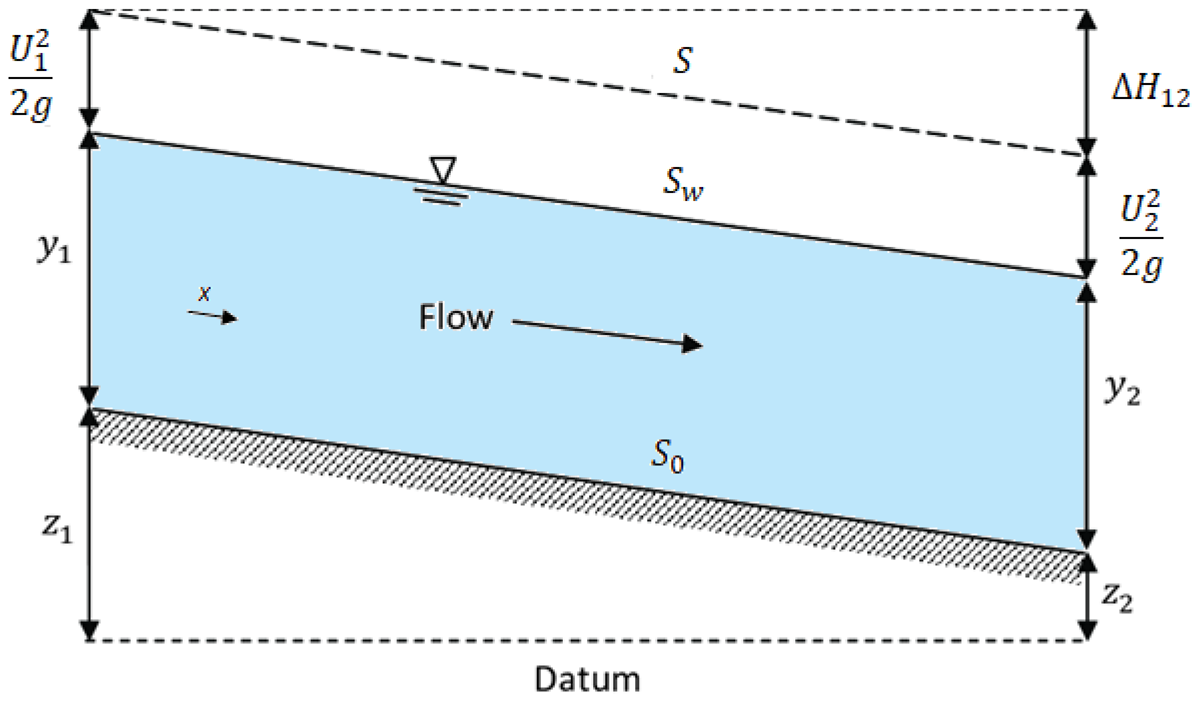
$\frac{dz}{dx} = -S_0$ Bed slope, positive downstream

$\frac{dy}{dx} = -S_w$ Surface slope, positive downstream

$\frac{\partial}{\partial x} = 0$ All the variables are constant along the longitudinal coordinate, *x*

e.g., $\frac{\partial S}{\partial x} = 0$

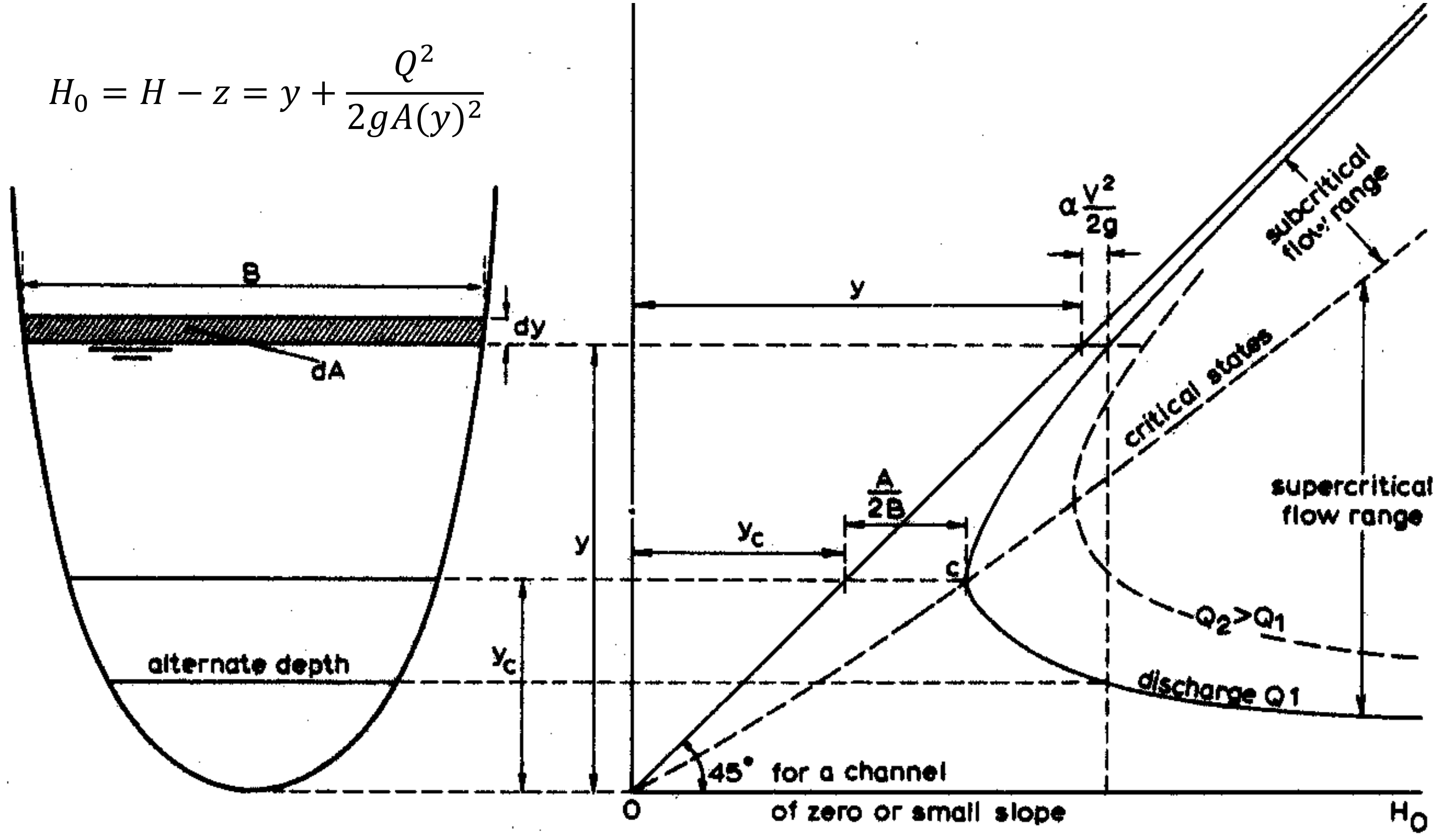
$$S = S_0 = S_w$$



Specific energy

H_0: average energy in a section of channel, relative to the bottom of the channel

$$H_0 = H - z = y + \frac{Q^2}{2gA(y)^2}$$



For a given channel, a given flow and a given specific energy, there are 2 conjugate depths, one corresponding to the torrential regime, the other to the fluvial regime.

$y > y_c$: fluvial regime

$y < y_c$: torrential regime

$y = y_c$: critical regime

$$y_c = y\left(\frac{\partial H_0}{\partial y} = 0\right)$$

For rectangular cross section $A(y) = B\,y$

$$y_c = \sqrt[3]{\frac{Q^2}{g\,B^2}}$$

At point C, the specific energy H_0 is minimal.

Point C is the critical point to which the critical height y_c corresponds.

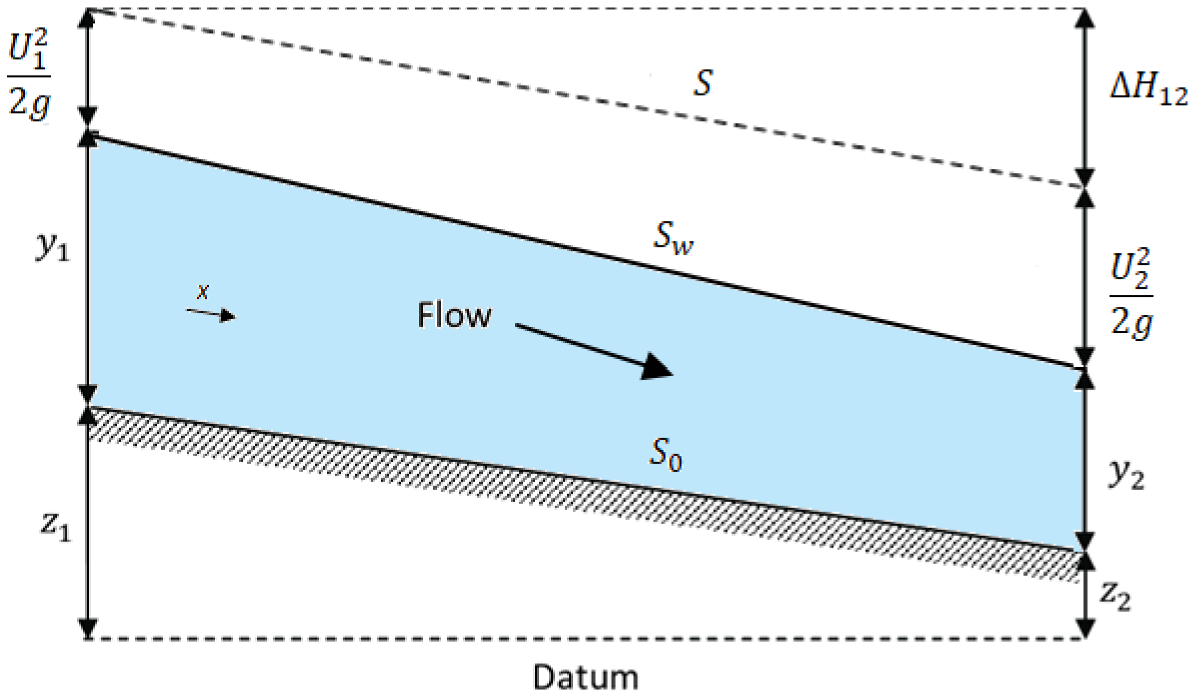
Permanent free-surface flow

Flow conditions= f
- flowrate
- channel characteristics (slope, roughness, geometry, etc.)
- presence of point structures and diversions

$$\frac{dQ}{dx} = 0$$

Flow discharge is constant

$$S \neq S_0 \neq S_w$$



Water surface profiles in permanent regime

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Total hydraulic energy per unit weight of water: $H = z + y + \frac{Q^2}{2g\,A^2}$

$$\frac{dH}{dx} = \frac{dz}{dx} + \frac{dy}{dx} + \frac{Q^2}{2g}\frac{d}{dx}\frac{1}{A^2} \quad \Rightarrow \quad S_0 - S = \frac{dy}{dx} - \frac{Q^2}{g\,A^3}\frac{dA}{dx}$$

By chain rule

$$S_0 - S = \frac{dy}{dx} - \frac{Q^2}{gA^3}\frac{dA}{dy}\frac{dy}{dx} \quad \Rightarrow \quad S_0 - S = \frac{dy}{dx} - \frac{Q^2 B}{gA^3}\frac{dy}{dx}$$

$\frac{dA}{dy} = B$ Channel width

$\sqrt{\frac{Q^2 B}{g\,A^3}} = Fr$ Froude number

$$\frac{dy}{dx} = \frac{S_0 - S}{1 - Fr^2}$$

We can make a qualitative analysis based on the sign of numerator N, and denominator D

e.g., $S_0 > S$ → N>0
$Fr > 1$ → D<0 → $\frac{dy}{dx} < 0$

Water surface profiles in permanent regime

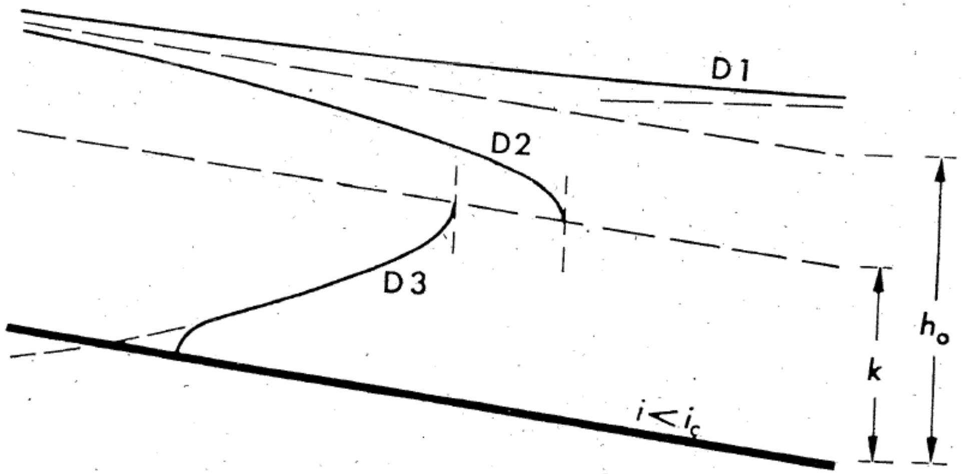


FIG. 10.21

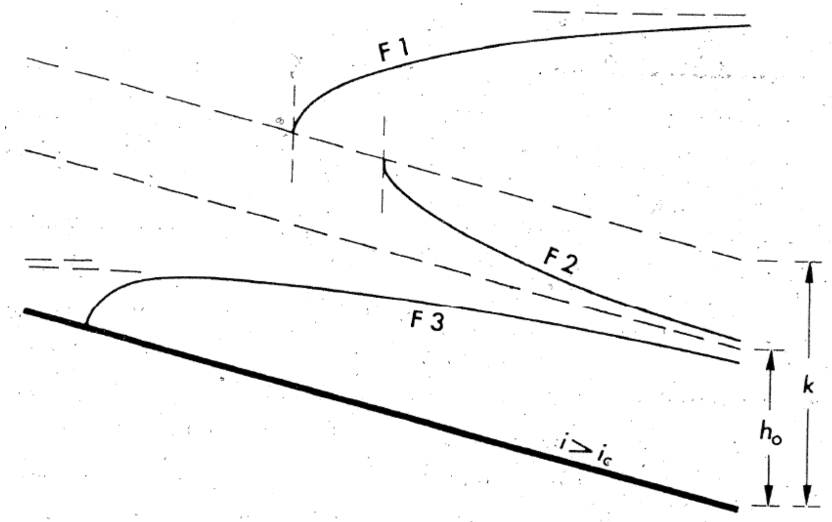


FIG. 10.22

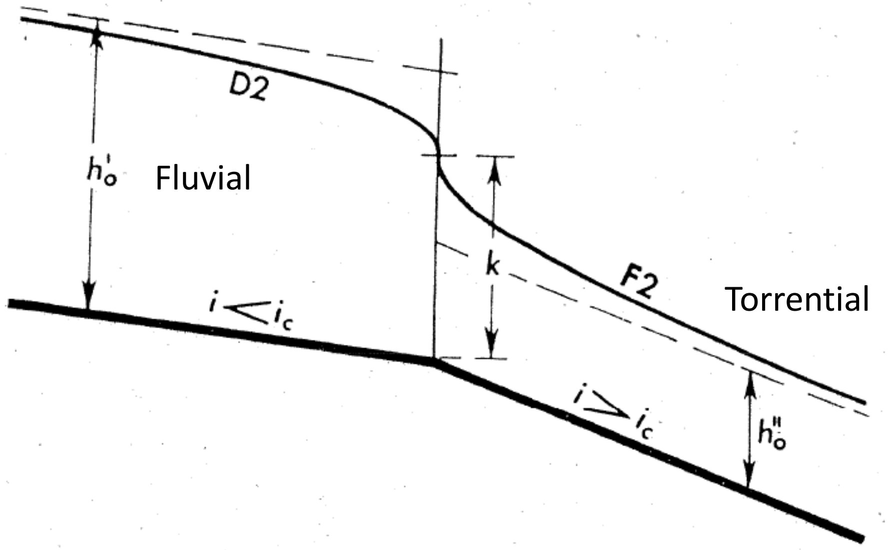


FIG. 10.26

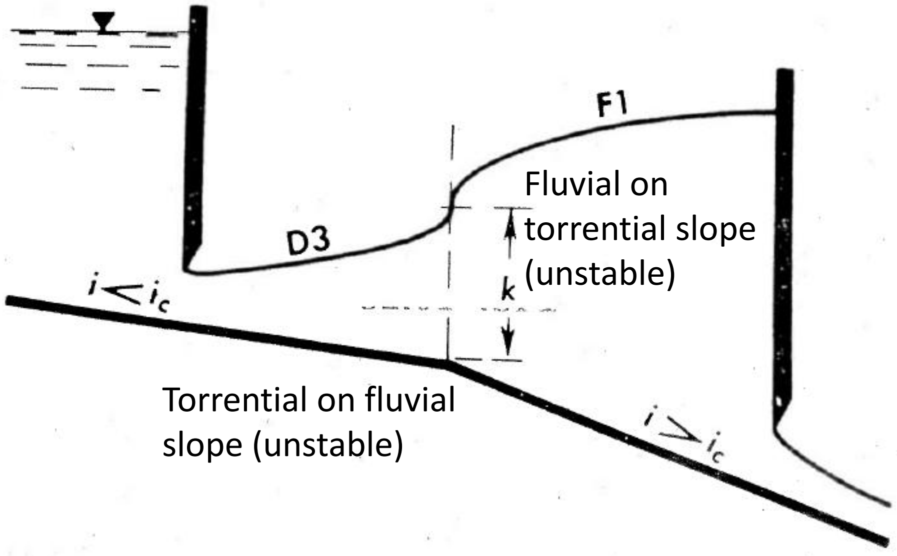


FIG. 10.27

Passage below a sluice gate

Hydraulic jump

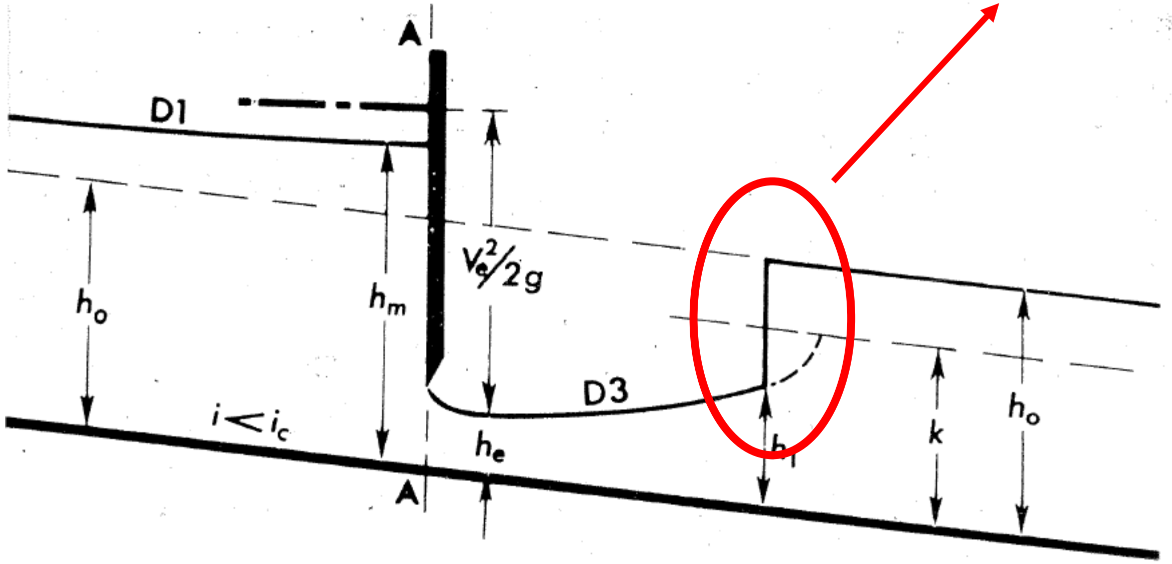


FIG. 10.34

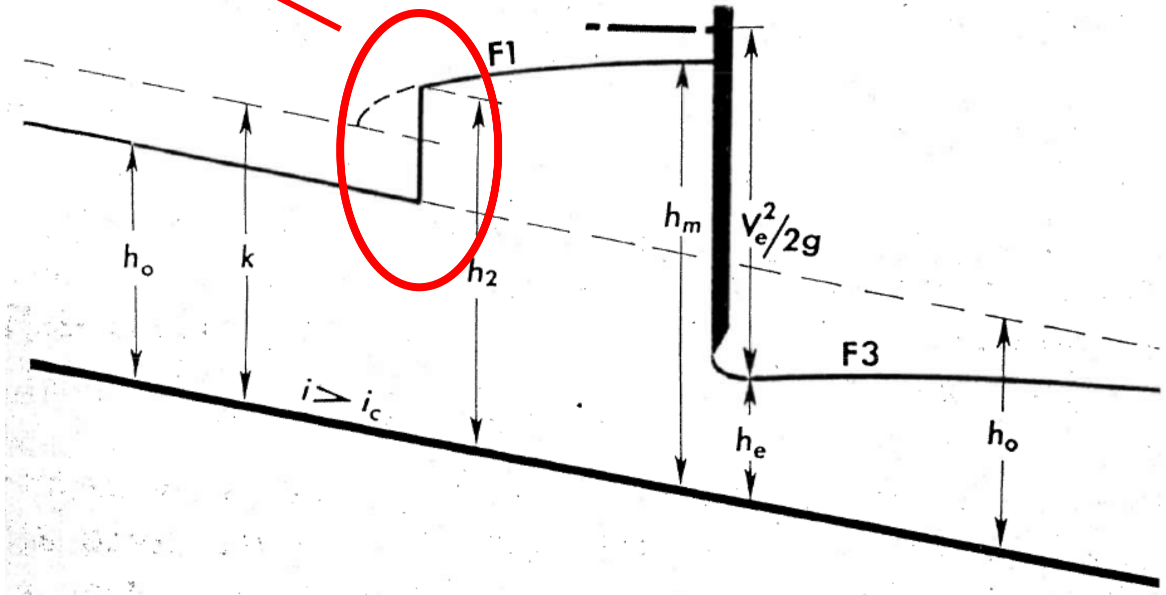


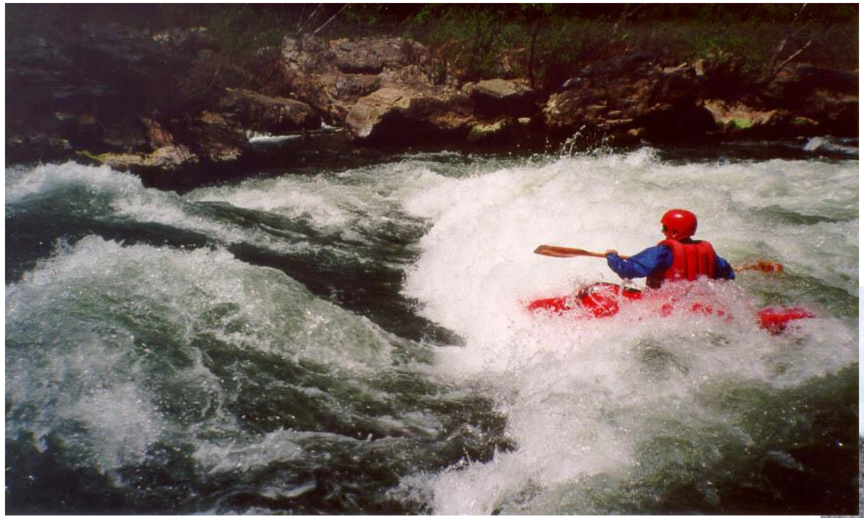
FIG. 10.36

Hydraulic jump

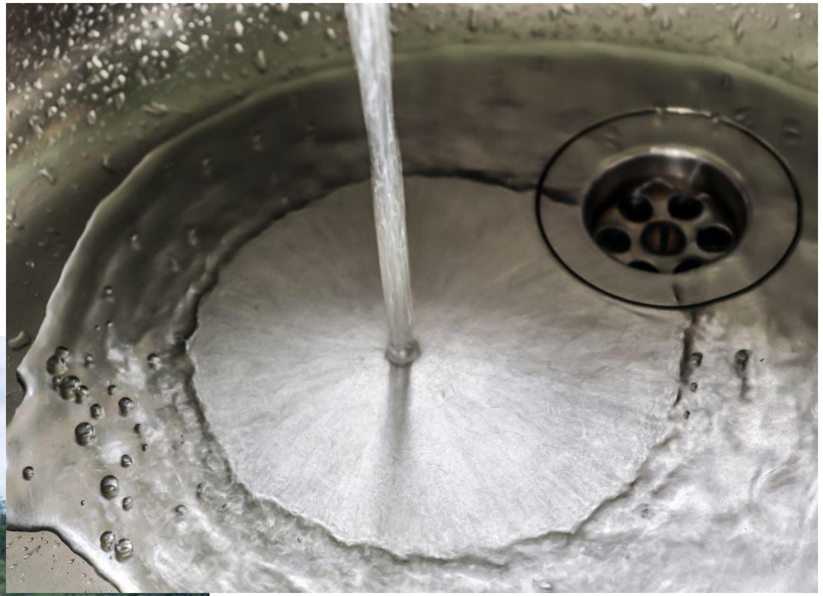
Abrupt transition from upstream supercritical flow to downstream subcritical flow

At home

In natural rivers



Downstream of weirs



Examples of hydraulic jumps

https://www.youtube.com/watch?v=7tjf8HWiR3Y

Passage below a sluice gate and lateral derivations

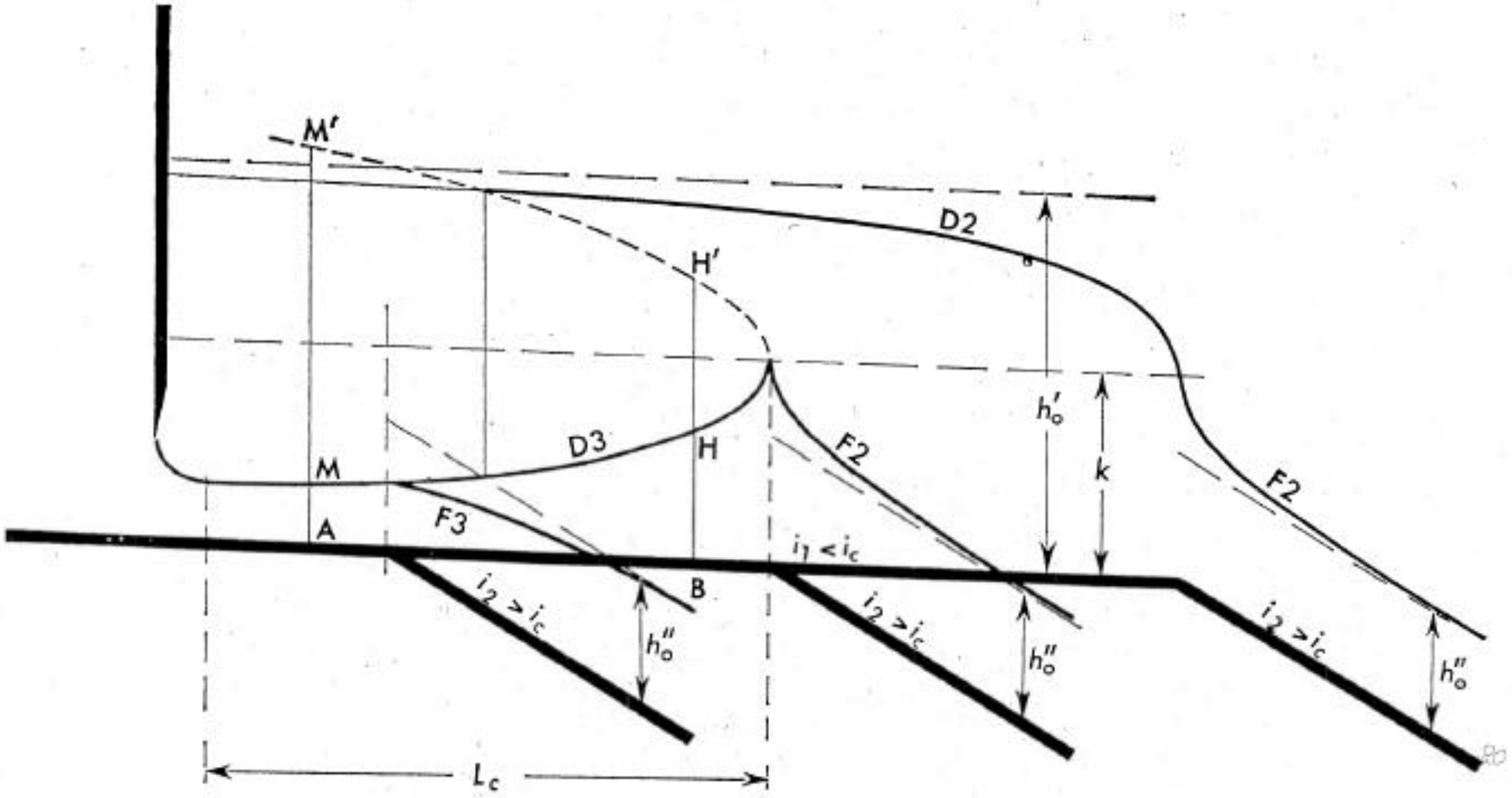


FIG. 10.38

Change of bed roughness – downstream increase

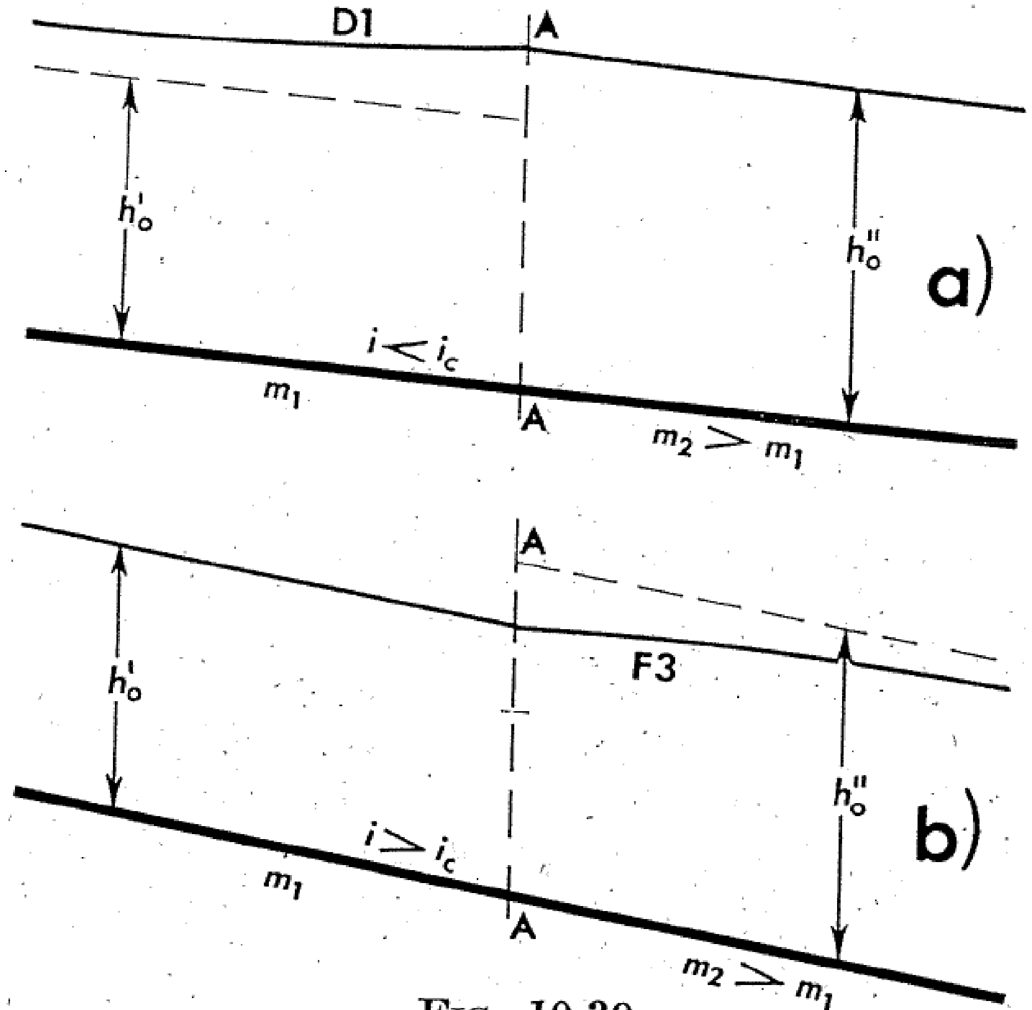


FIG. 10.39

Change of bed roughness – downstream decrease

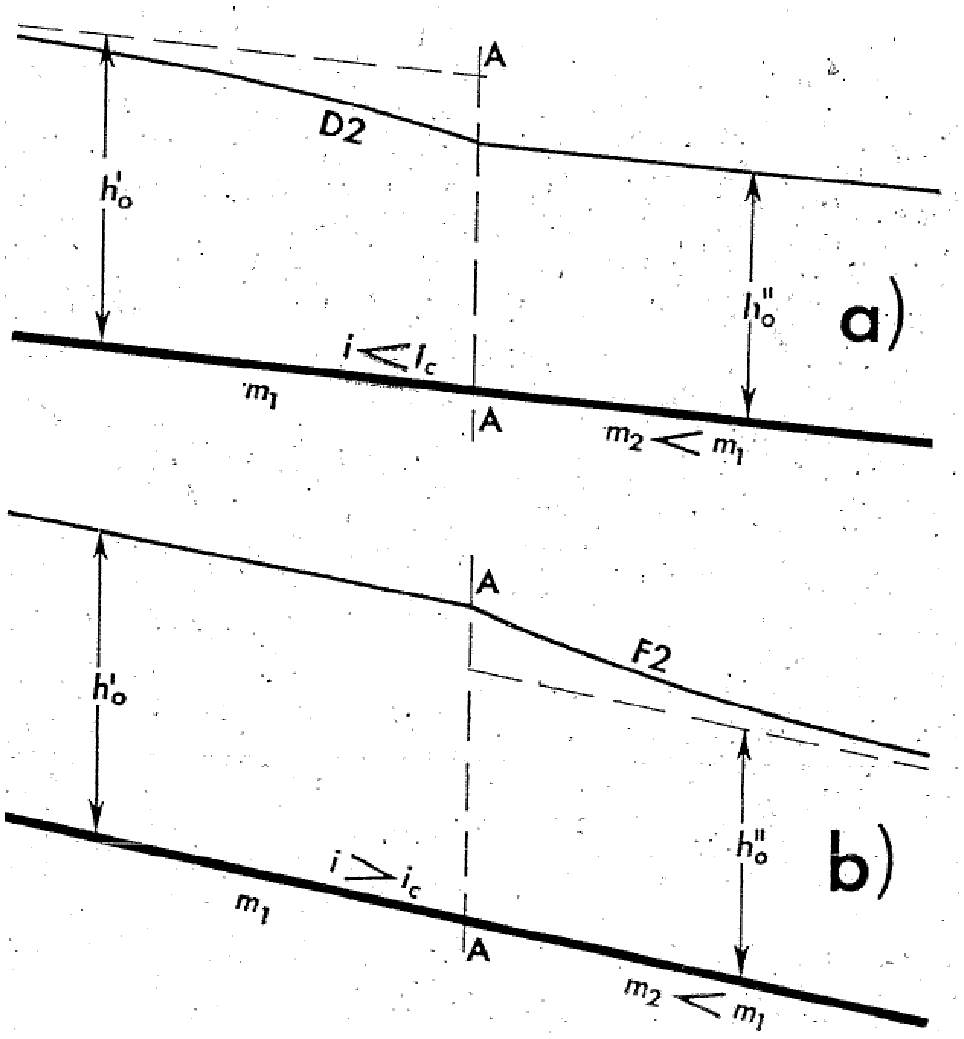


FIG. 10.40

EPFL

Passage over a low obstacle

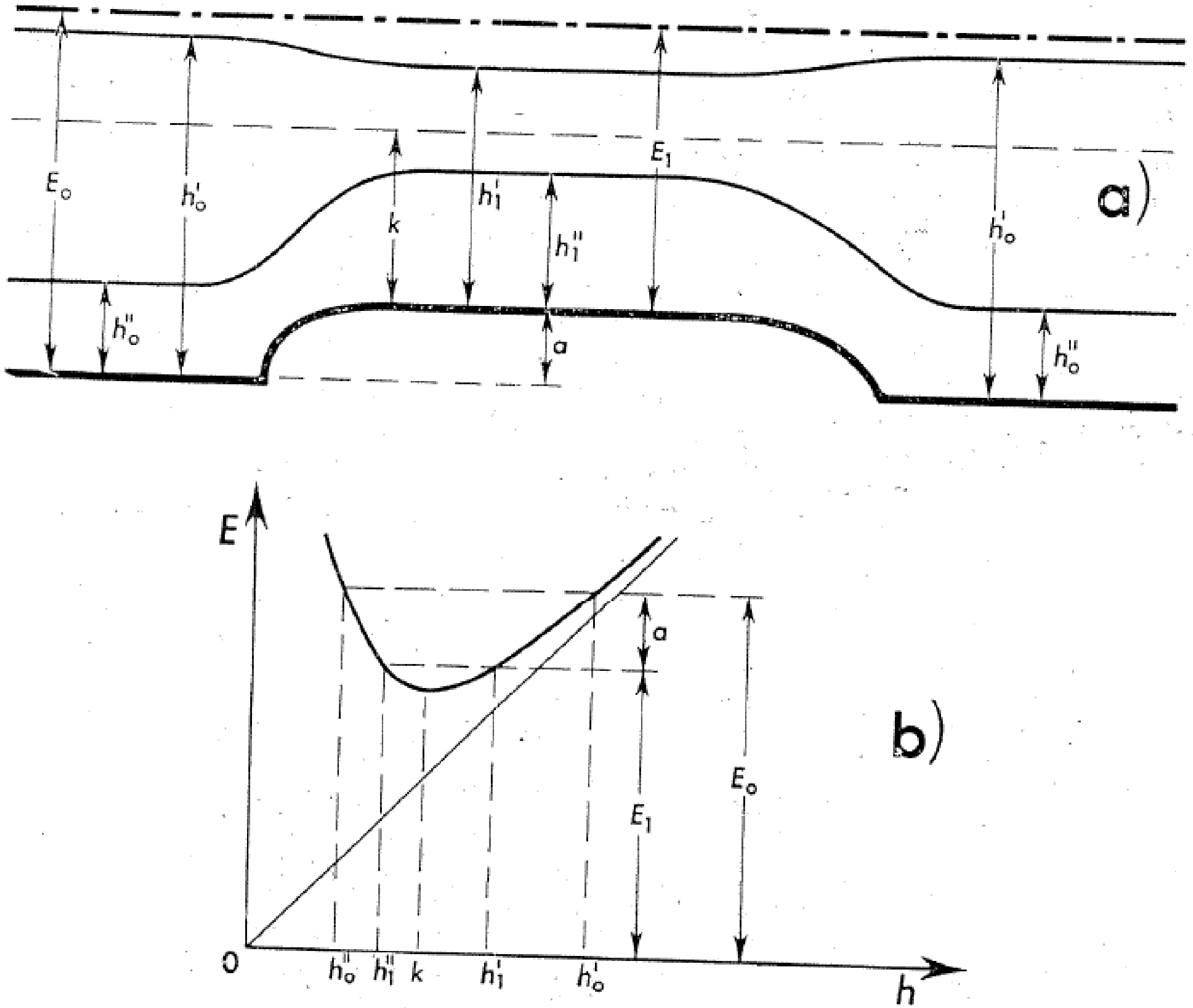


Fig. 10.41

a: height of the obstacle

Low obstacle

$H_0 - a > H_{\min}$

Passage over a high obstacle – fluvial regime

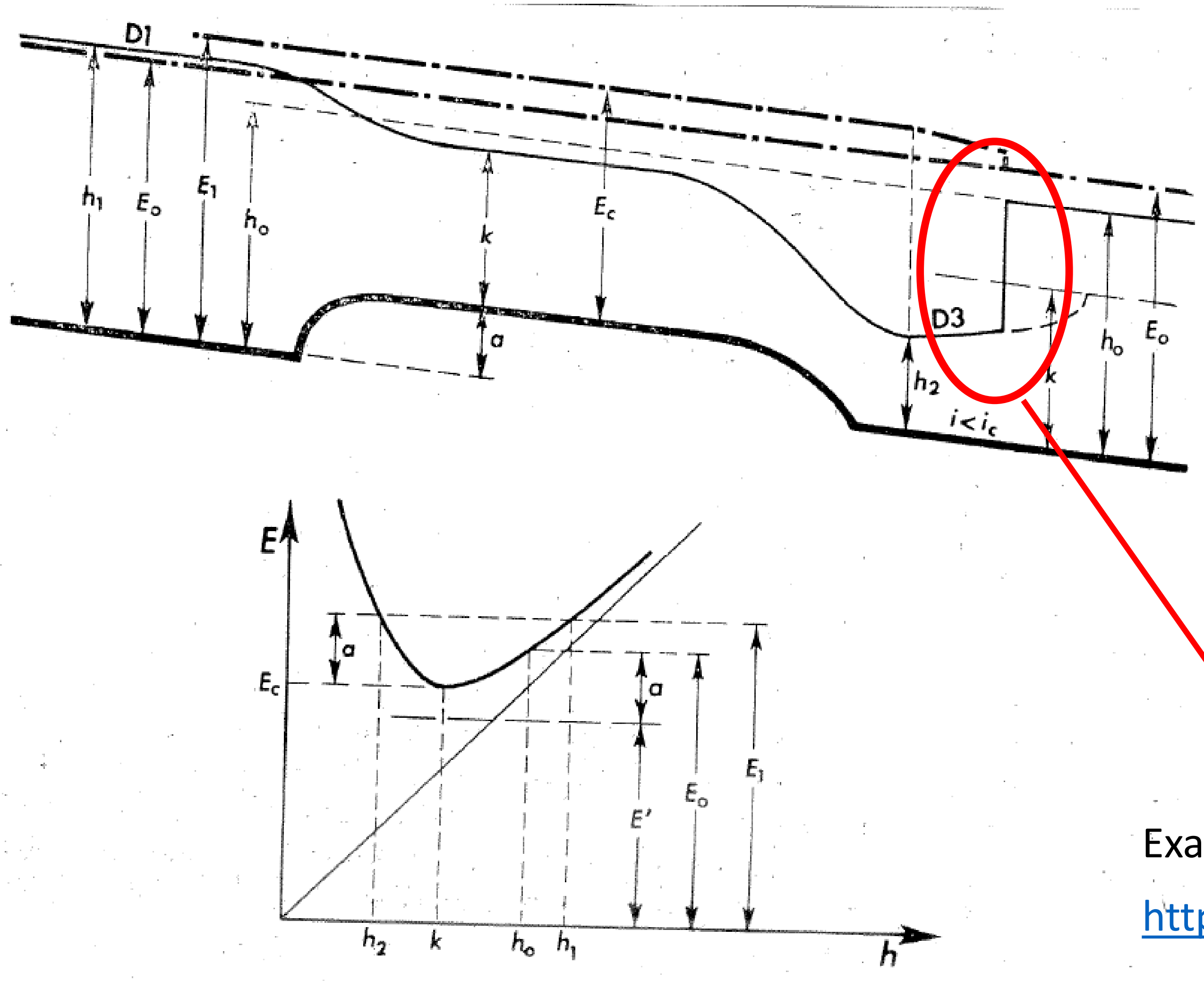


FIG. 10.42

a: height of the obstacle

High obstacle

$$H_0 - a < H_{\min}$$

Hydraulic jump

Example in a laboratory flume

https://youtu.be/xGTntCtQYmA?t=160

Passage over a high obstacle – torrential regime

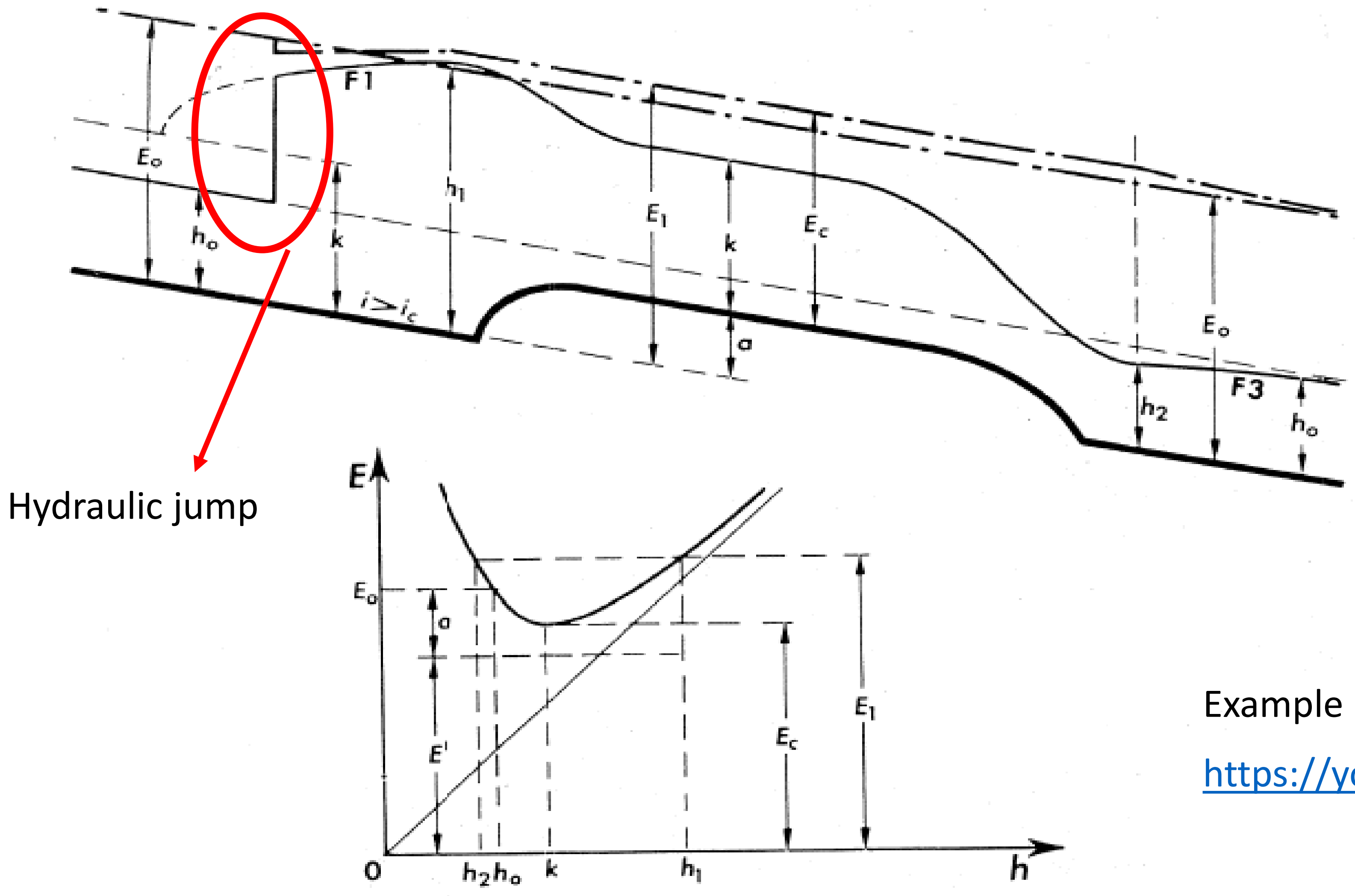


FIG. 10.43

a: height of the obstacle

High obstacle

$$H_0 - a < H_{\min}$$

Example in a laboratory flume

https://youtu.be/KzL4dPGmWss?t=420