Irrigation and Drainage Engineering

(Soil Water Regime Management)

(ENV-549, A.Y. 2024-25)

4ETCS, Master option

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Platform of Hydraulic Constructions

Lecture 4-2. Surface irrigation: hydraulic design of canals

Hydraulic design of canals

Longitudinal profile

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Water velocity v must remain within well-defined limits

v = f (slope, type of profile, geometry)

Velocity too small

- sediment deposit (periodic cleaning of deposited materials)
- generate canal oversizing
- increase the risk of waterborn diseases spreading (e.g., malaria)

$v_{min} > 0.5$ m/s

Velocity too high

- sediment movement and erosion risk
- torrential flow regime (hydraulic jumps)
- water splashes outwards
- increase the risk of waterborn diseases spreading (e.g., onchocerciasis)

Maximal velocity:

- Earthen canals = f (nature of profile materials and sediment load) $0.5 < v_{max} < 1$ m/s
- Concrete canals $v_{max} < 2$ m/s

Flow classification

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

Type of flow

- **permanent**
  - uniform
  - varied
    - gradually
    - suddenly
- **transient**

Flow regime

- **laminar**
- **turbulent**

Flow kinematics (Froude number Fr[1])

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

[1] compare l'énergie cinétique à l'énergie potentielle de l'eau
[2] les ondes ne peuvent pas se propager vers l'amont; y : hauteur d'eau; y_c : hauteur critique

Flow regime – Reynolds number

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

$\boxed{Re = v\, l / n}$ (v: mean flow velocity; l: characteristic dimension, n: coefficient of kinematic viscosity of water)

Channel flow :

$\boxed{Re = v\, R / n}$ (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.

Permanent free-surface flow

Flow conditions= f $\left\{ \right.$

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

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

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

$$H_o = y + \frac{v^2}{2g} = y + \frac{Q^2}{2gS^2}$$

The specific energy H_0 in a given section is therefore equal to the sum of the water height y and the kinetic energy charge (S: wetted section = f(y)).

The function $y(H_0)$ or H_0 (y), the specific energy curve or diagram, shows that 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.

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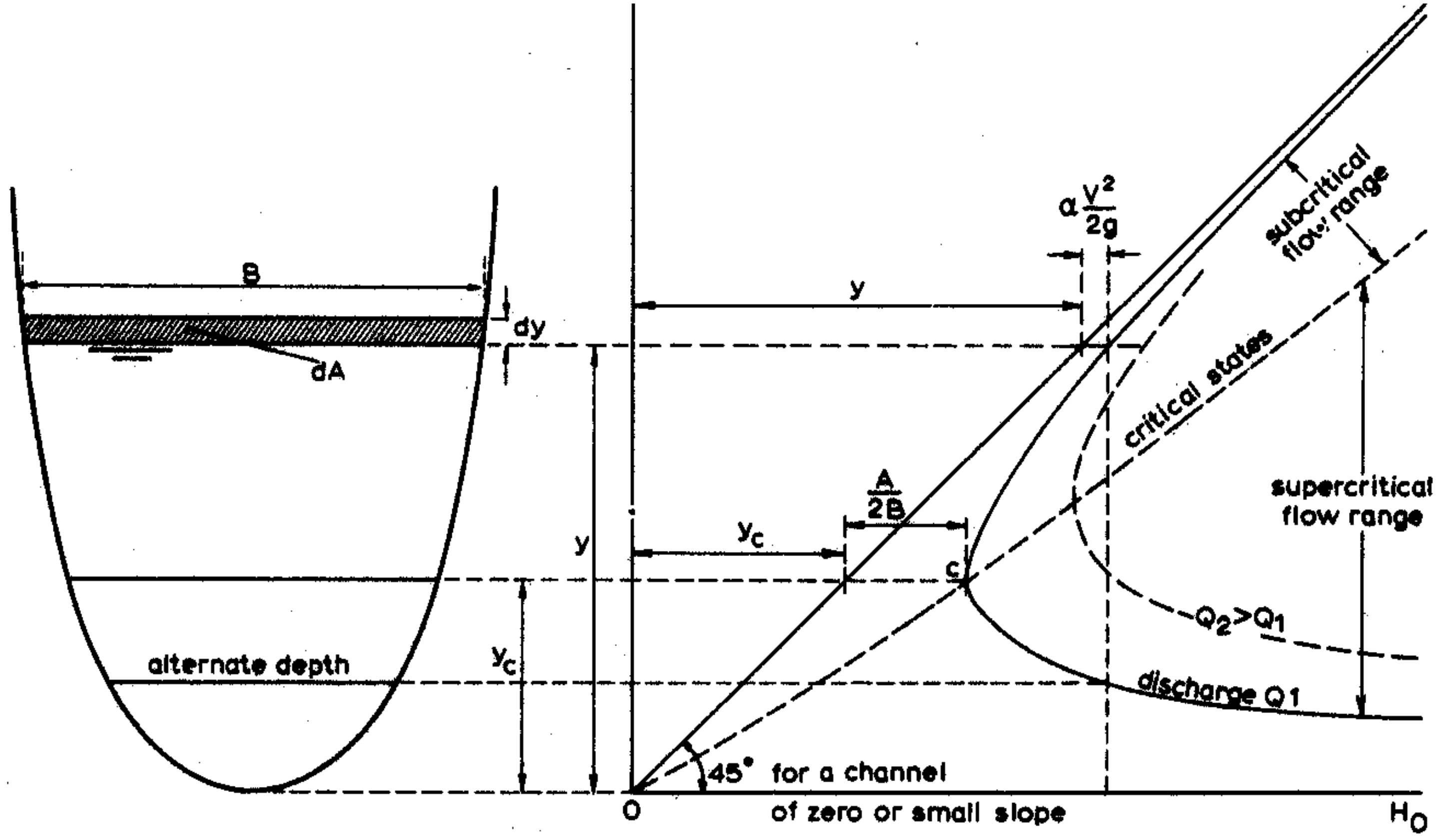
h: pressure load; z: gravity load = distance above the selected reference plane; Q: flow rate; S: wetted cross-section.

Specific energy diagram



$y > y_c$: fluvial regime

$y < y_c$: torrentiel regime

$y = y_c$: critical regime

At point C the specific energy is minimal; this is the critical point to which the critical height yc corresponds.

Water surface profiles in permanent regime

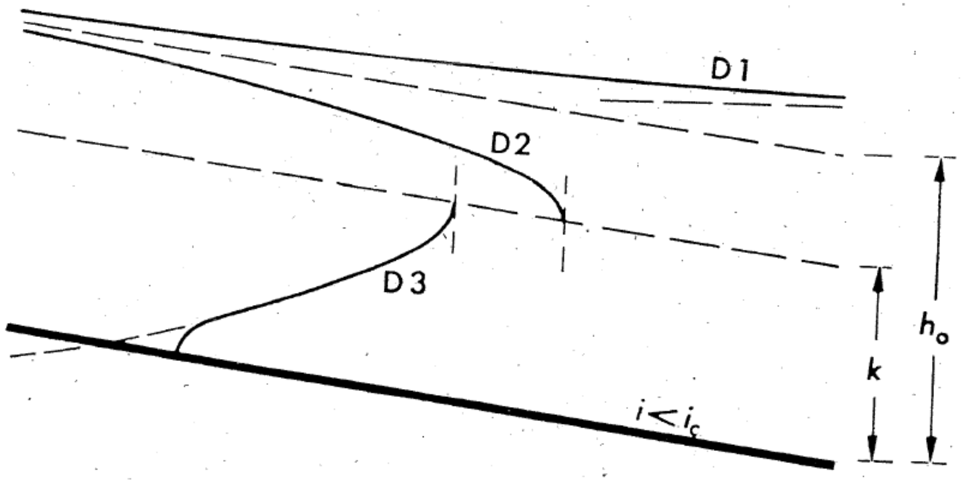


FIG. 10.21

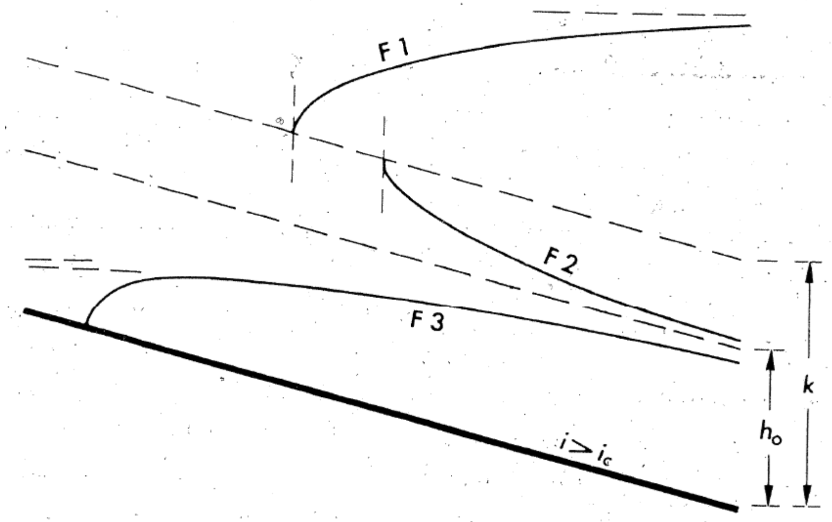


FIG. 10.22

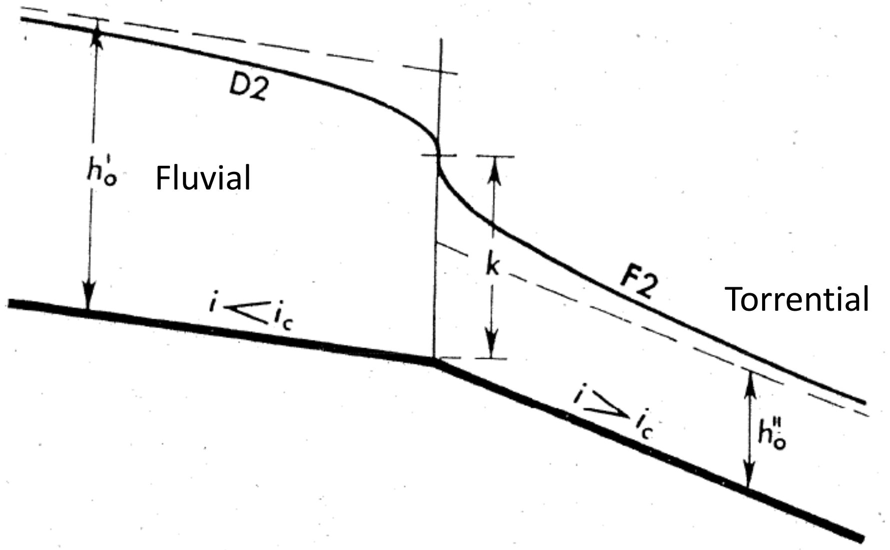


FIG. 10.26

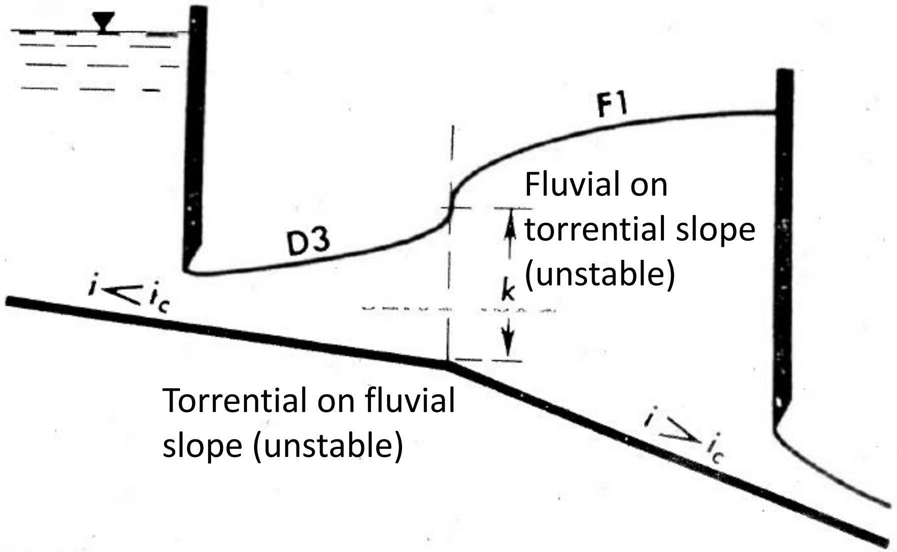


FIG. 10.27

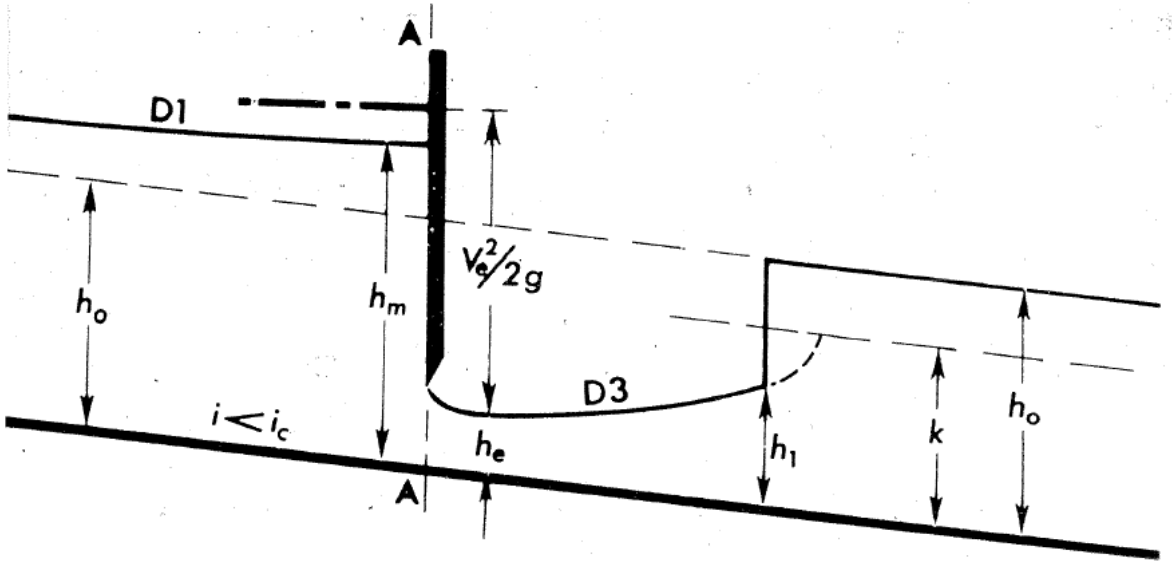


FIG. 10.34

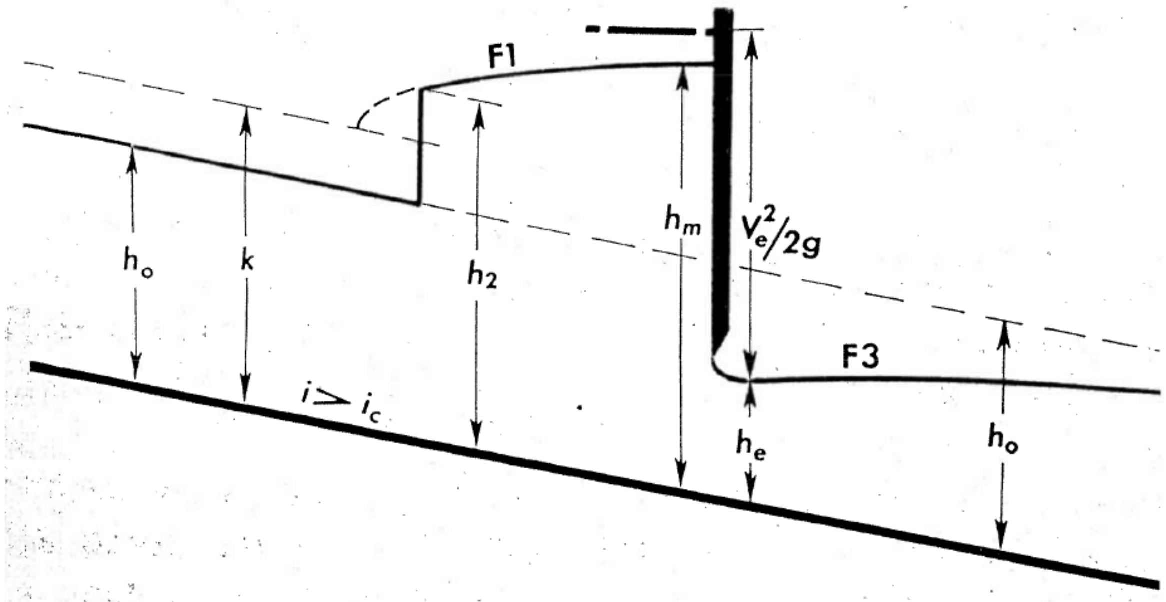


FIG. 10.36

PLATEFORME DE CONSTRUCTIONS HYDRAULIQUES

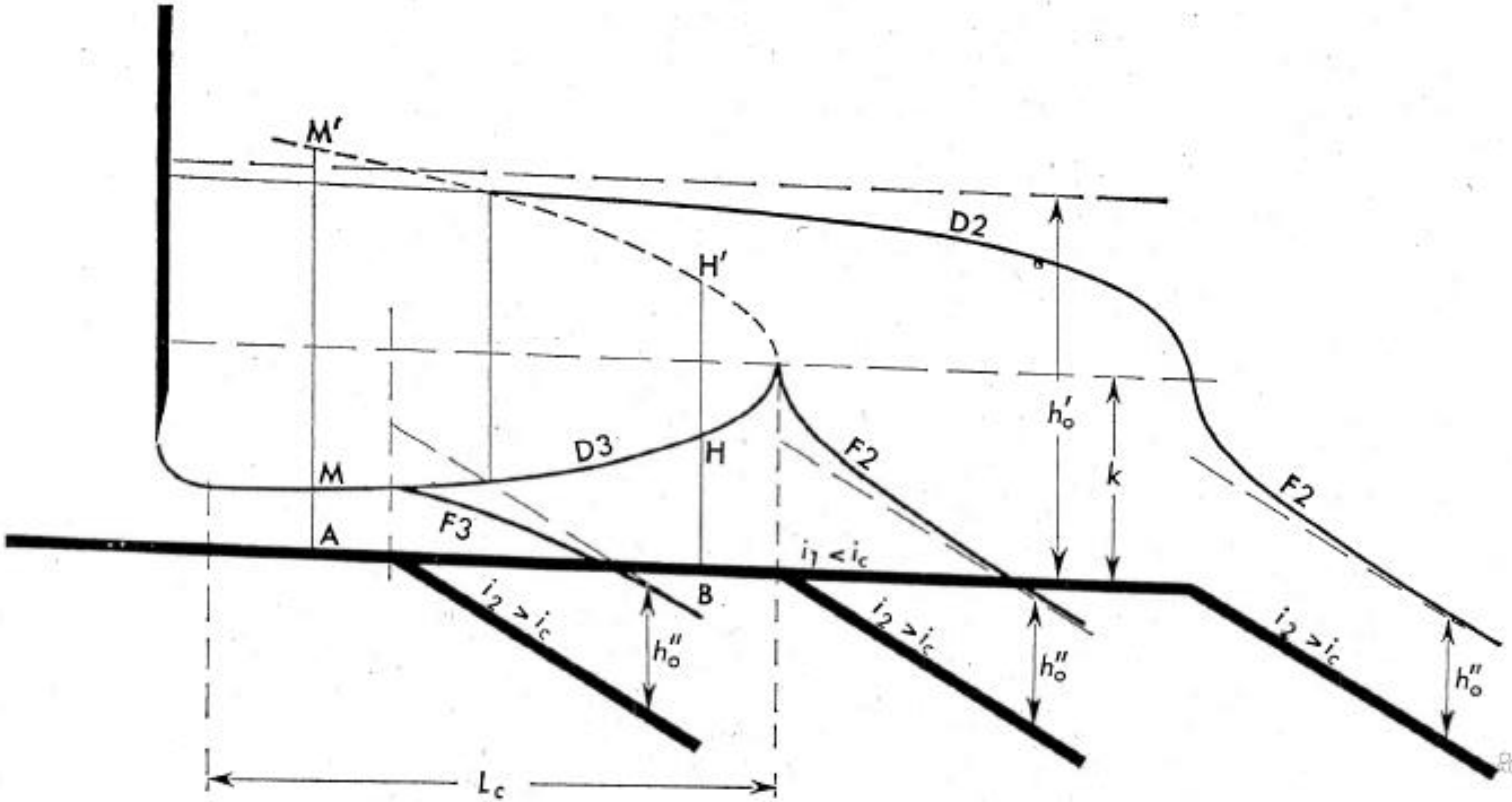


FIG. 10.38

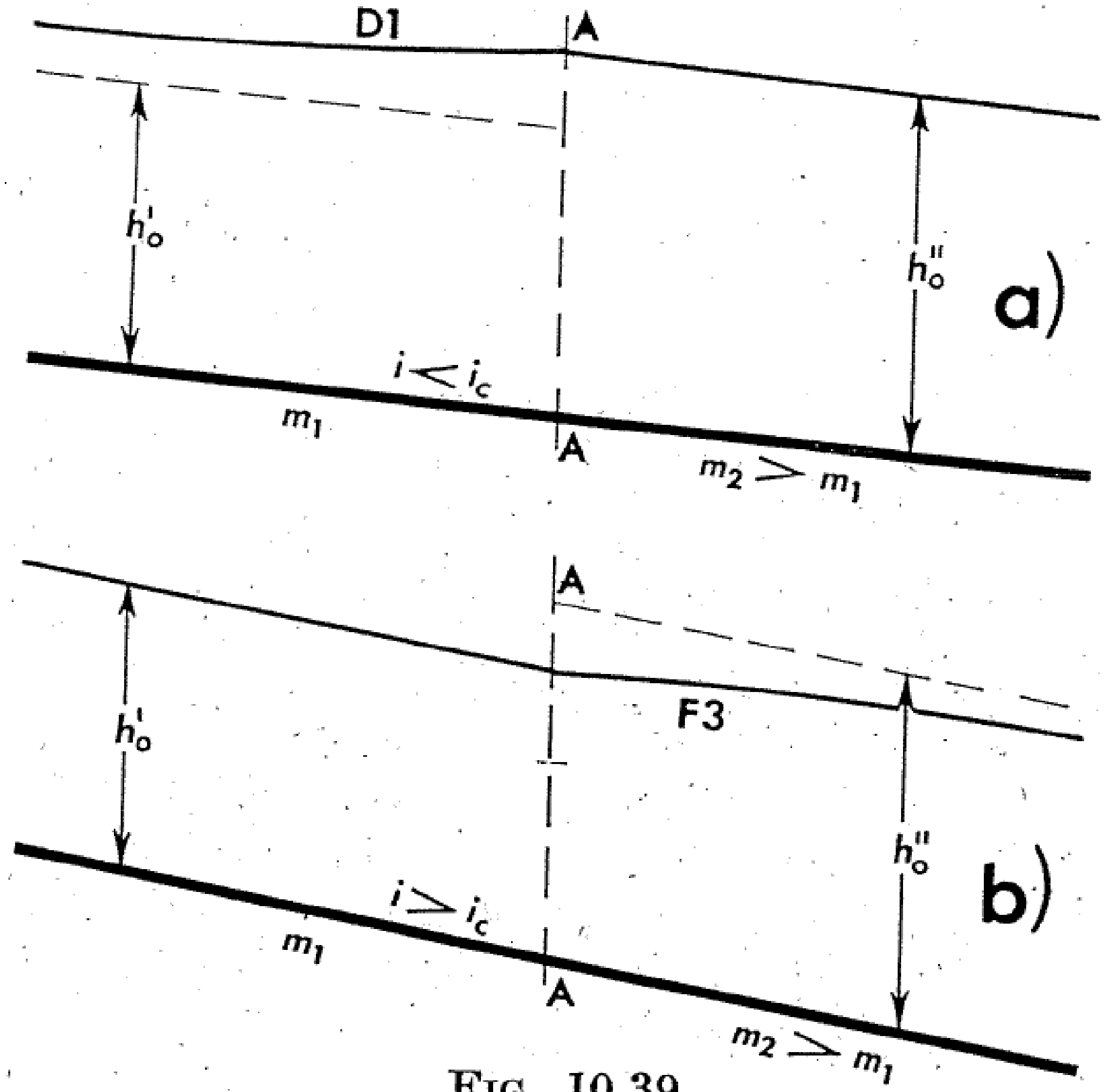


FIG. 10.39

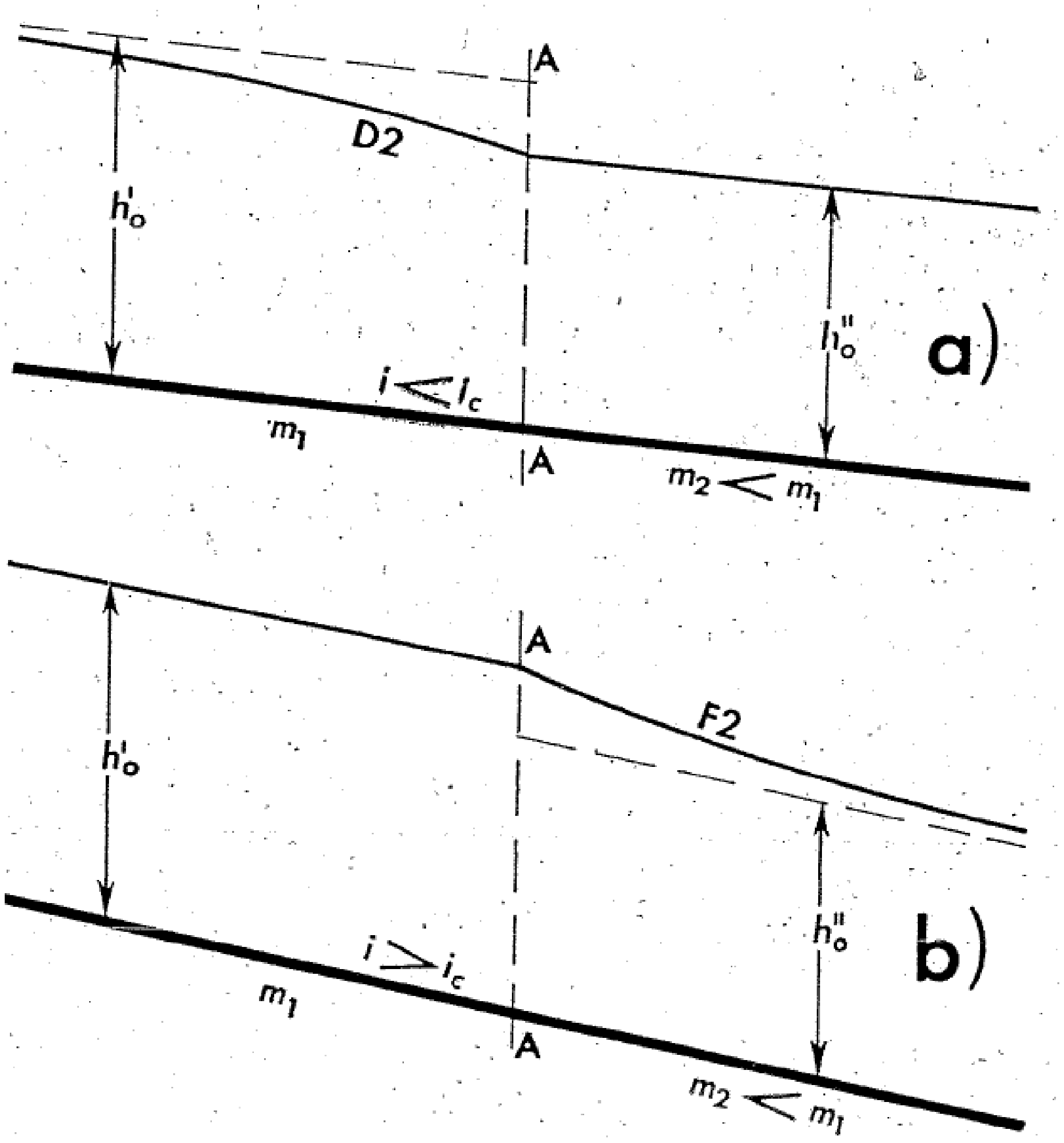


FIG. 10.40

Passage over an obstacle

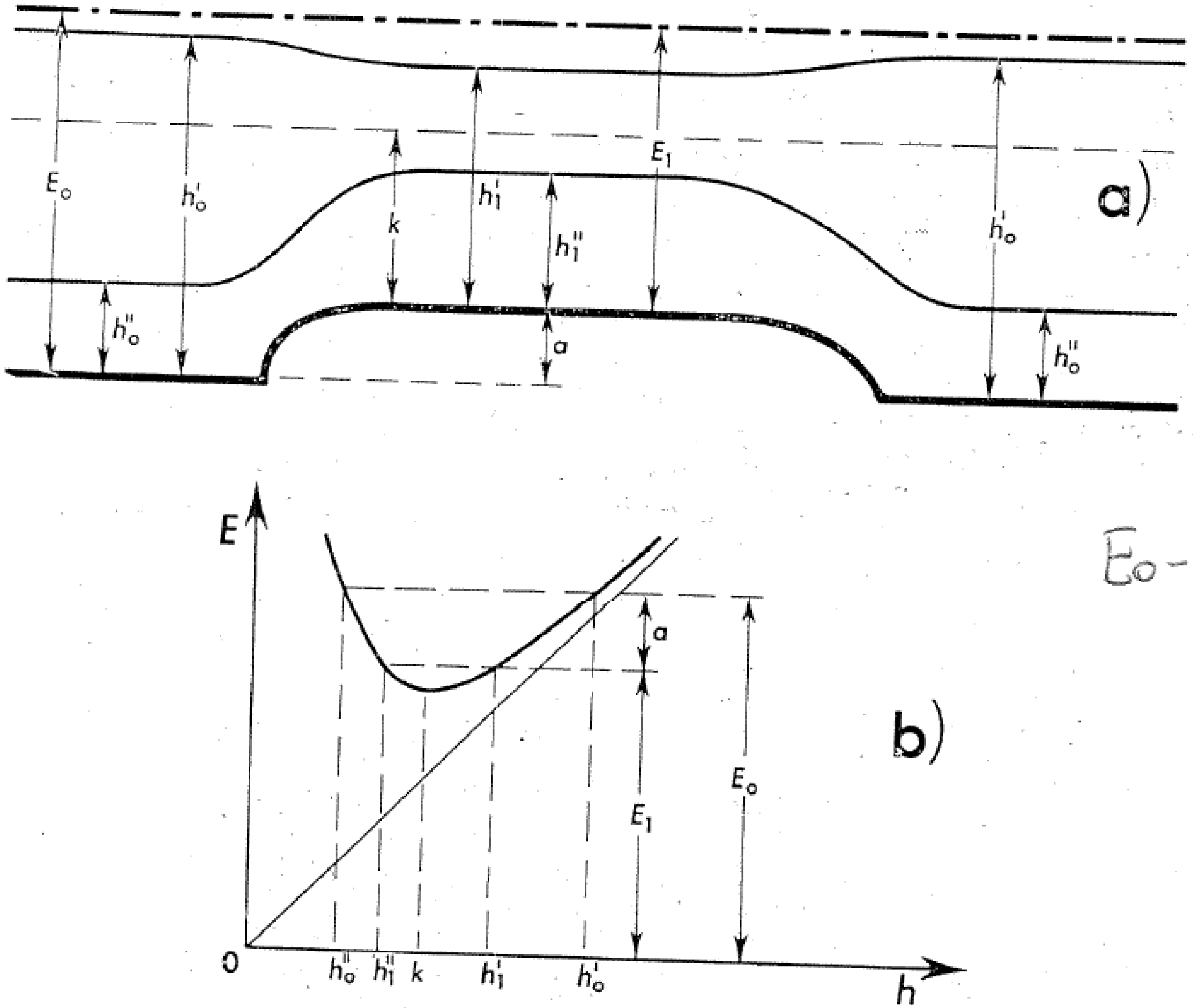


FIG. 10.41

$E_0 - a < E_0 - E_{h''}$

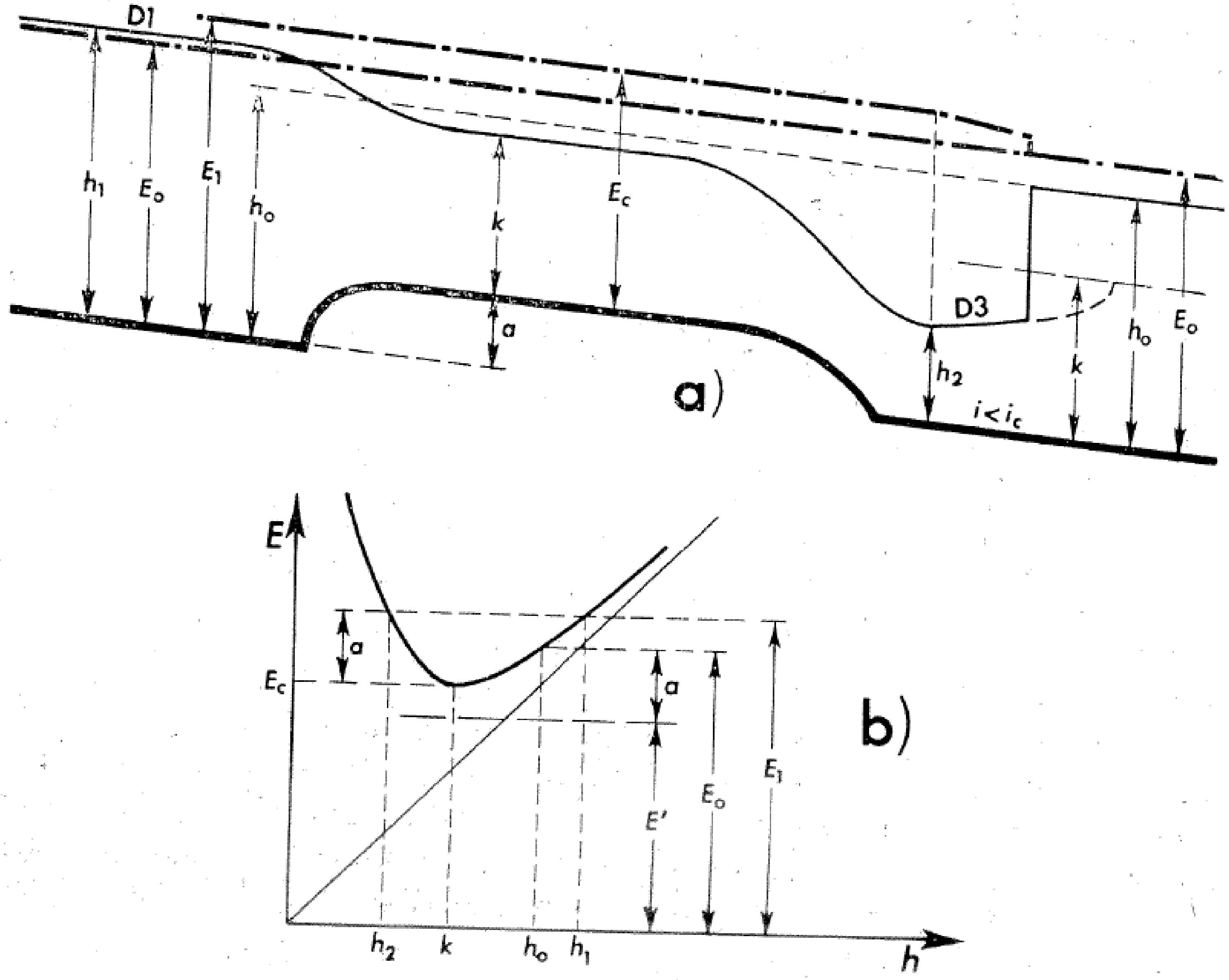


FIG. 10.42

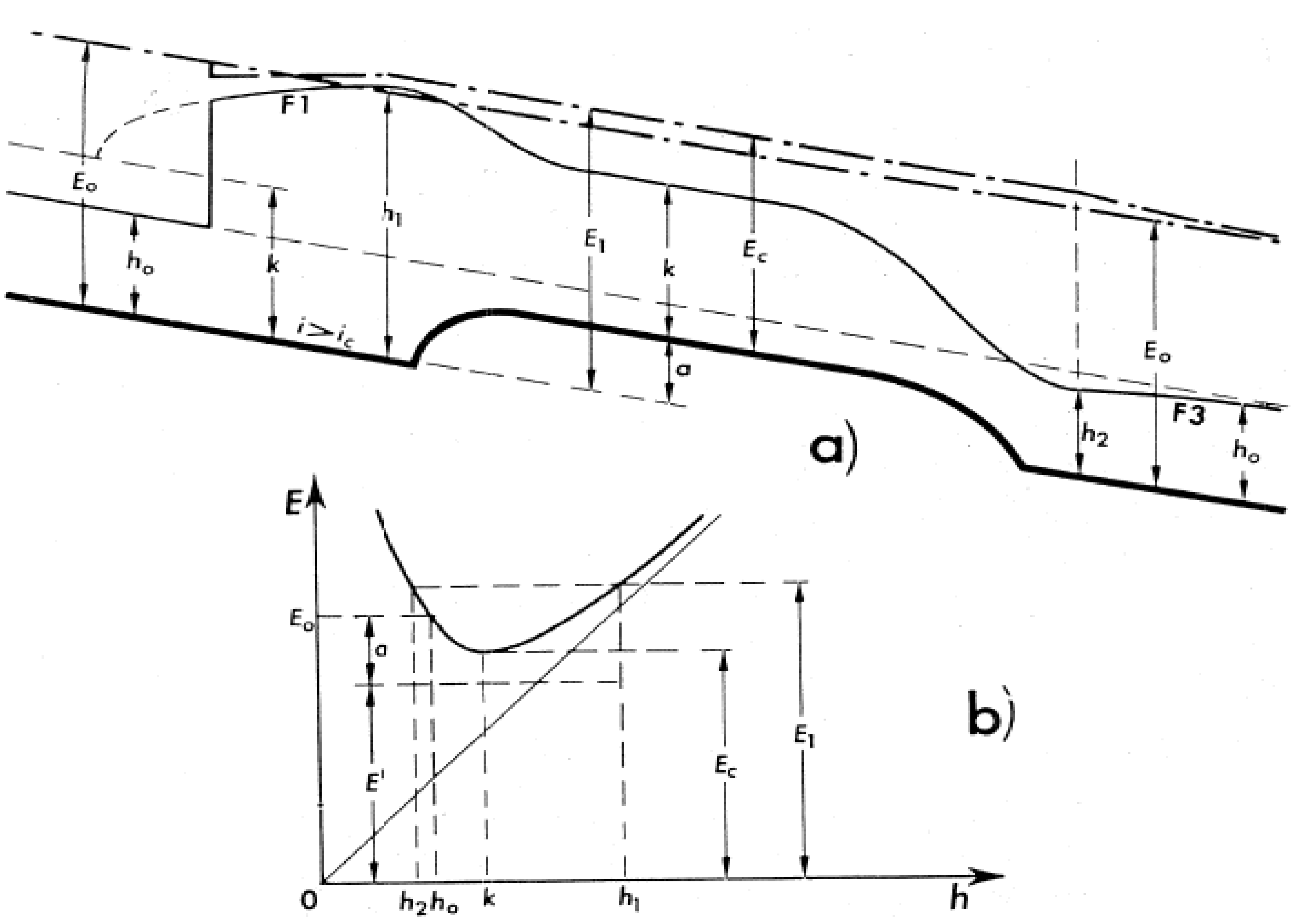
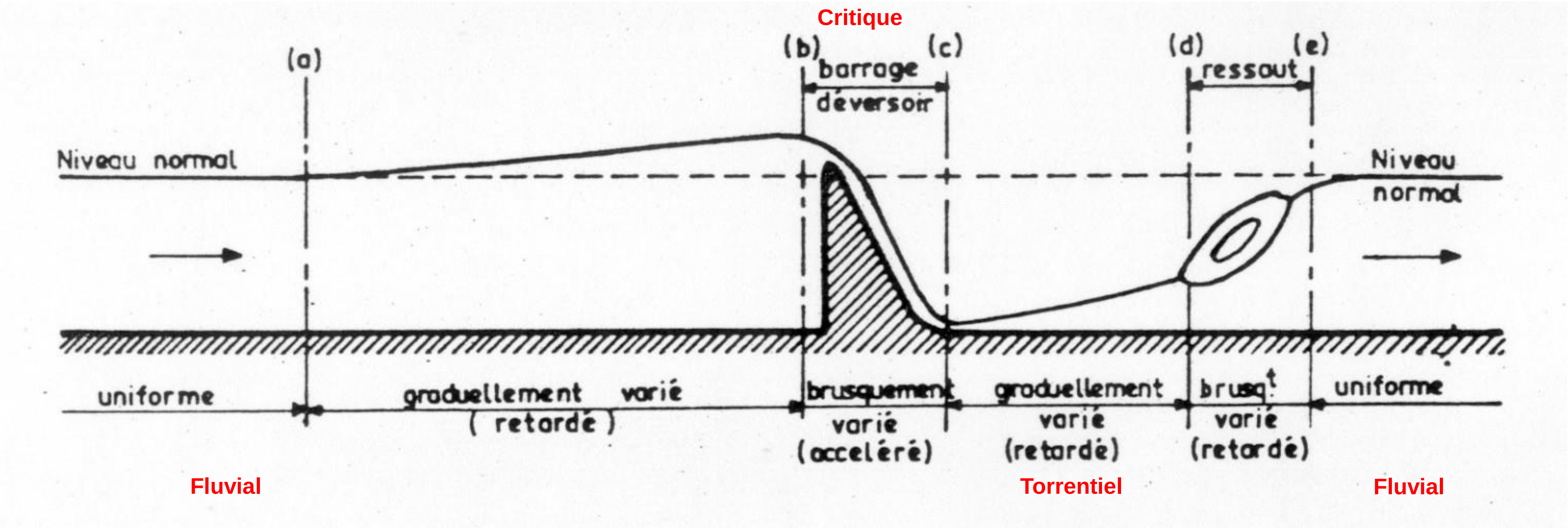


FIG. 10.43



Steady-state flow at a spillway dam, in a homogeneous channel with a gentle slope

Design (sizing) of a canal

Channel sizing frequently based on the assumption of uniform flow

Hypotheses

Flow conditions do not vary from one section to the next, so the channel must be long and homogeneous (straight section, constant slope and roughness).

Properties

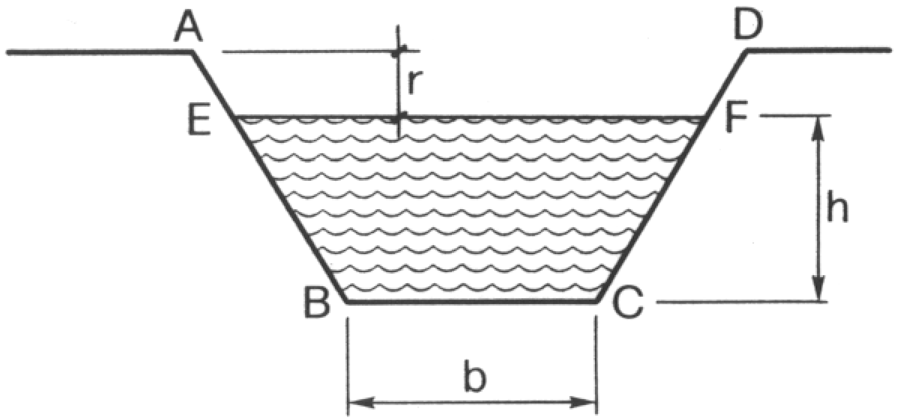
- the energy line is parallel to the free surface and the bottom of the channel (invert)
- the slope of the energy line *j* is equal to the slope s of the invert
- the head loss ΔH over a channel length L is $\Delta H = L\,j = L\,s$

Sizing

Empirical formulas: Manning-Strickler, Chézy, etc. (all valid in the rough turbulent flow regime)

Precision

Relatively low. It depends on the appropriateness of the roughness coefficient used and the plausibility of the assumptions.



Manning-Strickler formula:

$$Q = K\,A\,R^{2/3}\,S^{1/2}$$

K : roughness coefficient ($m^{1/3}/s$)

10	<	K	<	100
Ditch in poor condition, overgrown with vegetation				Smooth cement walls in perfect condition

At the pre-project stage, we frequently adopt

- Concrete channels : $60 < K < 70$ [$m^{1/3}/s$]
- Earthen canals : $30 < K < 40$ [$m^{1/3}/s$]

Value of the Manning-Strickler roughness coefficient K ($m^{1/3} s^{-1}$) for some common material and applications

Nature des "parois mouillées"	État des parois			
	Parfait	Bon	Assez bon	Mauvais
Tuyaux:				
en fonte, sans enduit	83	77	71	67
en fonte, avec enduit	91	83 *	77	-
en acier	77	67 *	59	-
Canaux revêtus:				
Parois en ciment lissé	100	91	83	77
Canaux revêtus de béton	83	71 *	63	56
Moellons bruts cimentés	59	50	40	33
Pierres sèches	40	33	30	29
Canaux et fossés non revêtus:				
en terre, rectilignes et uniformes	59	50	44 *	40
en terre, à larges méandres	44	40 *	36	33
à fond en terre, berges en galets	36	33	30 *	27
Cours d'eau naturels:				
Berges propres et rectilignes	40	36	33	30
Berges propres et rectilignes mais avec quelques herbes et pierres	33	30	29	25
Canaux naturels avec méandres et endroits peu profonds	30	29	25	22
Zones avec beaucoup de végétation	13	10	8	7