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 6-1. Sprinkler irrigation: basis, techniques and materials

Advantages

- more efficient than gravity methods
- no soil preparation required
- suitable for most soils
- makes it possible to dose inputs accurately
- small footprint
- can be used to combat frost

Disadvantages

- cost of installation; relatively advanced technology
- high operating costs if pumping required
- can encourage the development of diseases on certain crops;

  if salt water is used, damage to plants with sensitive foliage
- sensitive to wind
- poorly suited to sloping soils

Main components of sprinkler irrigation networks

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- ➔ intake
- ➔ pressurisation unit
- ➔ network of pressurized pipes
- ➔ spraying equipment

Rational for using suspended reservoirs

- ➔ ensure that the water is regularly under pressure
- ➔ capping peak demands
- ➔ optimise supply systems
- ➔ overcoming minor incidents

} Large reservoirs

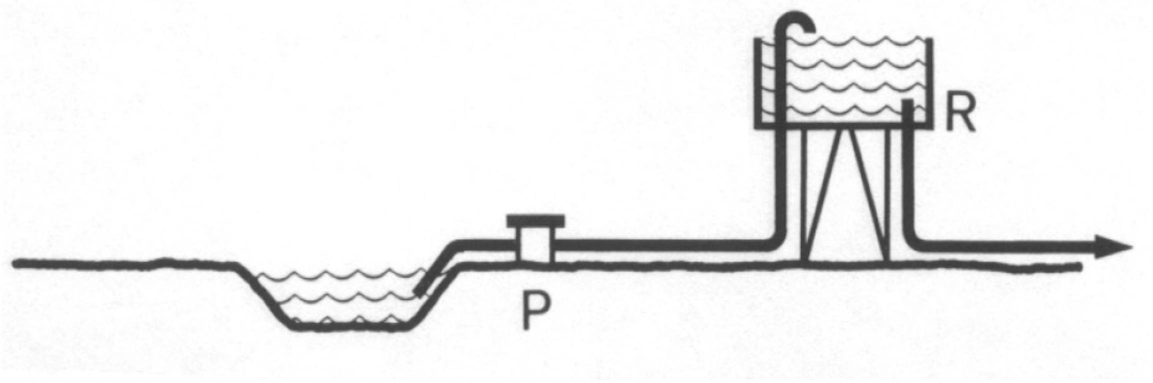


Fig. 1 : Cas du réservoir surélevé

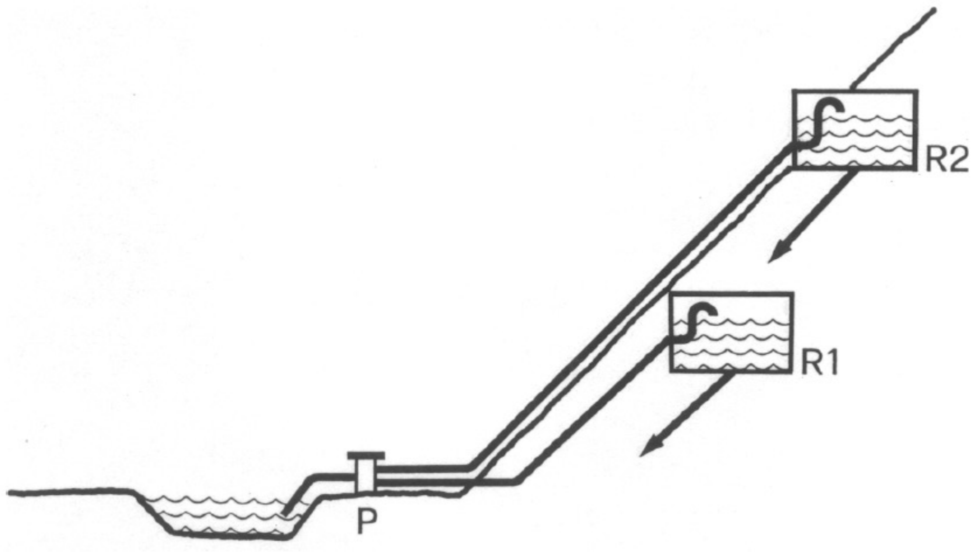


Fig. 3 : Alimentation étagée

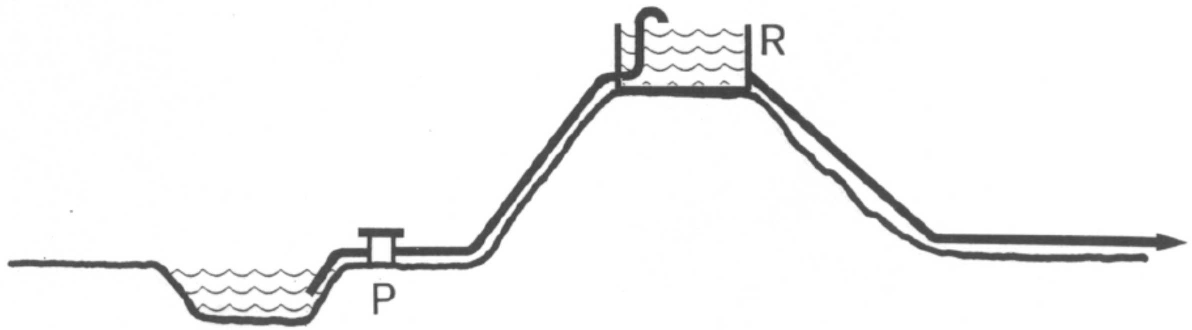
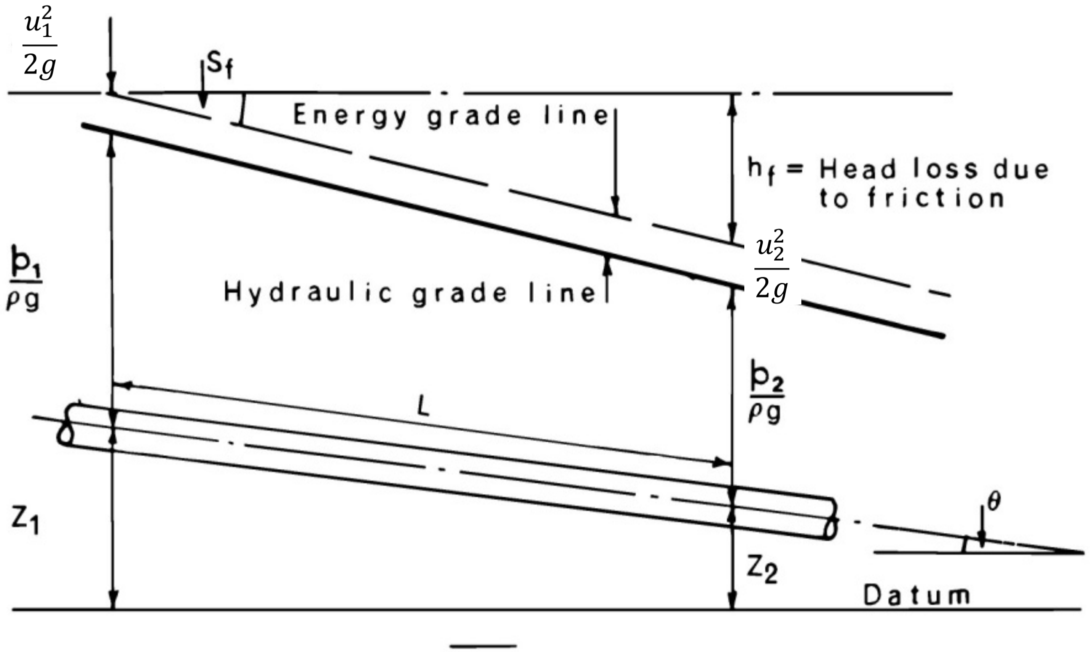


Fig. 2 : Cas du réservoir d'écrêtement

Fig. 4 : Refoulement direct

Energy and hydraulic grade lines



$$H_u = \frac{\bar{u}^2}{2g}$$

$$H_p = \frac{p}{\gamma} = \frac{p}{\rho g}$$

$$\frac{\bar{u}_1{}^2}{2g} + \frac{p_1}{\rho g} + z_1 = \frac{\overline{u_2}^2}{2g} + \frac{p_2}{\rho g} + z_2 + h_f$$

Hydraulic gradient is the plot of potential energy, i.e. $\frac{p}{\rho g} + z = h_p$ against distance

Energy gradient is the hydraulic gradient plus the velocity head, i.e. $H = \frac{u^2}{2g} + \frac{p}{\rho g} + z$

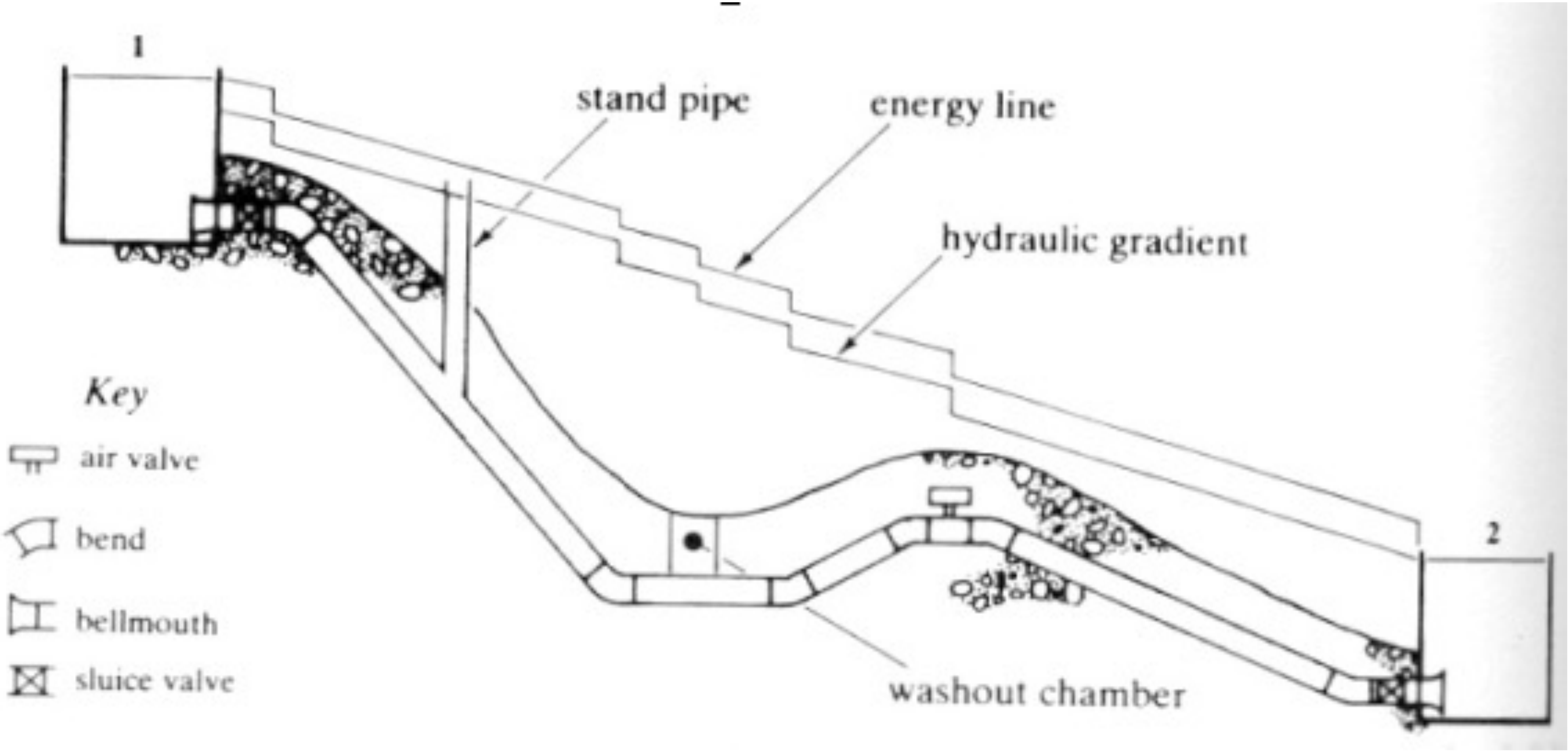
The motion of a fluid implies that a distributed dissipation *j* per unit length *x*,

$$j = -\frac{\partial H}{\partial x}$$

$h_f = j\,L$

Gravity flow mains

Notie: in this figure entrance and exit local dissipations as well as distributed losses in both the entrance and exit pipes are here not shown



"Hydraulically long" pipes or pipelines

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Definition: A pipe is called 'hydraulically long', regardless the presence of a weak discontinuity in the geometry which induces a localized head loss, if the total pipe length is at least $L > 20\,L^*$, i.e. $L > 1000d$.

$L^* = D/\lambda$

For pipelines the hydraulically-long pipe assumption generically holds

For pipelines the EGL and HGL are basically coincident as the kinetic term is negligible compared to other losses

Hydraulic functioning of pipelines

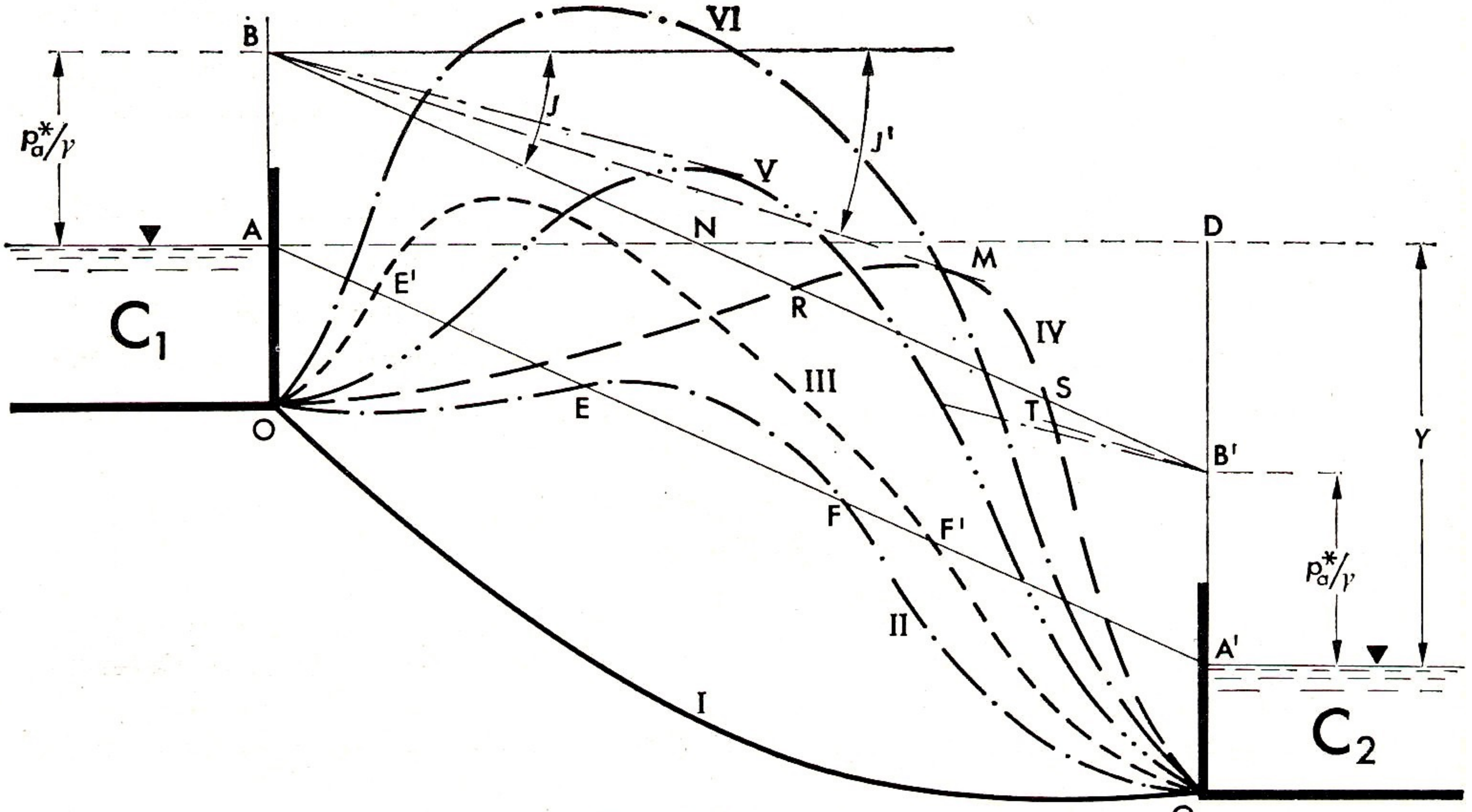

FIG. 8.13

Hydraulic design of pipes and conduits

Diagnostic (or verification) versus design problems

- Notice, that by using the continuity equation for the pipe, $Q = u\frac{\pi D^2}{4} = const$, the energy balance equation can be rewritten in terms of flow rate, Q thus allowing for calculating the flow rate once the geometry of the pipe system (lengths, diameters, restrictions, etc), the pipe roughness and the available energy are known (verification problem). Similarly, if the flow rate is known, one can compute the diameter to convey it with the assigned available energy (design problem). We can summarize the two problems as

GENERAL VERIFICATION PROBLEMS	GENERAL DESIGN PROBLEM
⇓	⇓
KNOWN: D, L, i, ε or equivalent roughness	KNOWN: Q, L, i, ε or equivalent roughness
⇓	⇓
UNKNOWN: effective flow rate Q passing within the pipe of diameter D with the established dissipation per unit lengh i	UNKNOWN: best diameter D (pipe size) to convoy the flow rate Q with the established dissipation per unit length i

Review of general hydraulics

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$$Q = V\,S$$

$$j = \frac{\lambda}{D}\frac{V^2}{2g} \quad \text{(Darcy-Weisbach eq.)}$$

$$j = \frac{\lambda}{D}\frac{Q^2}{2gS^2}$$

j : distributed energy loss per unitary length

λ : Friction factor (distributed unitary loss compared to kinetic energy term)

Friction factor and link to flow regime

- **Laminar regime :** $\lambda = \frac{64}{Re}$ **(Poiseuille equation)**
- **Turbulent regime:** $\frac{1}{\sqrt{\lambda}} = -2\log\left(\frac{\varepsilon}{3.7\,D} + \frac{2.51}{Re\,\sqrt{\lambda}}\right)$ **(Colebrook et White)**

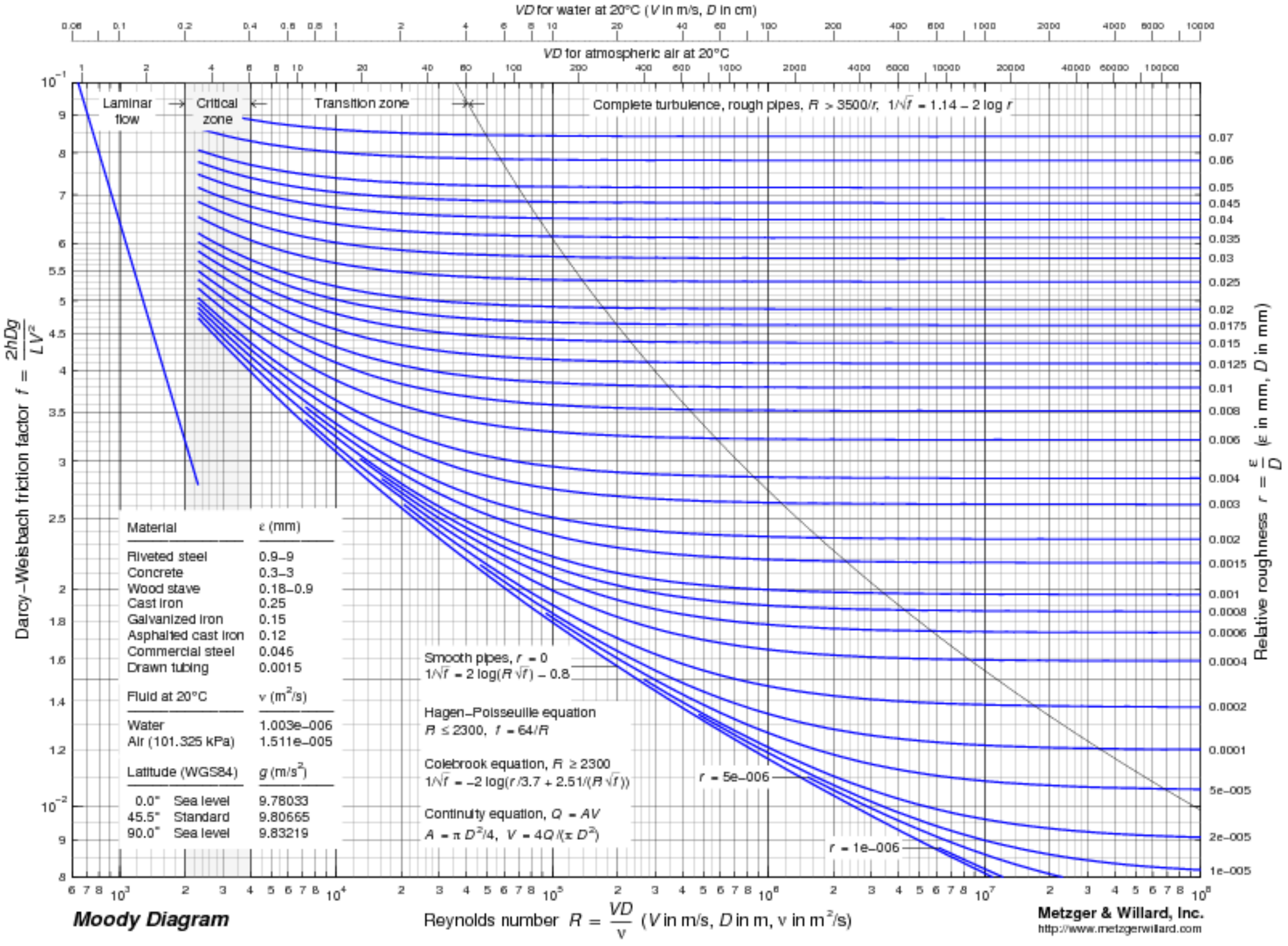
ε : pipe roughness

Re *: Reynolds number

Remember the Moody's diagram!

* Laminar regime is valid when **Re = VD/n < 2000**

The Moody Diagram



Formulae for the friction factor λ (or *f*)

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- Colebrook-White equation: $$\frac{1}{\sqrt{f}} = -2\ Log\left(\frac{\varepsilon}{3.71D} + \frac{2.51}{Re\sqrt{f}}\right)$$

- Moody equation: $\lambda = 0.0055\left[1 + \left(\frac{20000\ \varepsilon}{D} + \frac{10^6}{R_e}\right)^{1/3}\right]$

±5% accuracy for Re 4000 to 10^7 & ε /D < 0.01

- Barr formula: $\frac{1}{\sqrt{\lambda}} = -2log\left(\frac{\varepsilon}{3.7D} + \frac{5.1206}{{R_e}^{0.89}}\right)$

1% accuracy for Re > 10^5

- Darcy-Weisbach formula for h_f: $h_f = \frac{\lambda L u^2}{2gD}$

Indicative values for absolute roughness ε for different types of pipe

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Nature	ε en m		
Verre	de l'ordre de 10^{-7}		
Tuyau étiré en cuivre ou laiton	de l'ordre de 10^{-6}		
Tuyau en PE ou PVC	10^{-5}	à	10^{-6}
Acier, neuf	10^{-4}	à	$5 \cdot 10^{-5}$
Acier, légèrement rouillé	$5 \cdot 10^{-4}$	à	$1.5 \cdot 10^{-5}$
Acier, incrusté	$1.5 \cdot 10^{-3}$	à	$3 \cdot 10^{-3}$
Fonte revêtue intérieurement PUR	$< 10^{-5}$		
Fonte neuve bitumée intérieurement	10^{-4}	à	$1.5 \cdot 10^{-4}$
Fonte neuve, non revêtue	$2.5 \cdot 10^{-4}$		
Fonte âgée et incrustée	$1.5 \cdot 10^{-3}$	à	$3 \cdot 10^{-3}$
Béton neuf et lisse	$0.3 \cdot 10^{-3}$	à	$0.8 \cdot 10^{-3}$

Pipe Material	k_s (mm)
Brass, copper, glass, perspex	0.003
Asbestos cement	0.03
Wrought iron	0.06
Galvanised iron	0.15
Plastic	0.03
Bitumen-lined ductile iron	0.03
Spun concrete lined ductile iron	0.03
Concrete sewer in poor condition	6.0

Pipes in service for several years : $\varepsilon = 2 \cdot 10^{-3}$ m

Formulas for *j* (dissipation per unit length)

- These are practical formulas only valid in the fully turbulent regime (rough turbulent flow region)

DARCY-WEISBACH

$$j = \beta \frac{Q^2}{d^m} \quad \textit{where if} \quad \begin{cases} \beta = \beta' & \Rightarrow m = 5.33 \\ \beta = \beta_i(d) & \Rightarrow m = 5 \end{cases}$$

CHEZY

$$\bar{u} = C\sqrt{R\,j} \quad \textit{where}$$

$$C = \frac{87}{1+\frac{\gamma_B}{\sqrt{R}}} \qquad \textit{Bazin}$$

$$C = \frac{100}{1+\frac{m_K}{\sqrt{R}}} \qquad \textit{Kutter}$$

$$C = c_{GS} R^{1/6} \qquad \textit{Gaucler-Strikler}$$

$$n = 1/c_{GS} \qquad \textit{Manning}$$

Hydraulic design via the Manning/Strickler formula

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$$j = \frac{Q^2}{K_s^2 \, R^{4/3} \, S^2}$$

j : distributed loss per unit length

Q : flowrate in m^3/s

R : hydraulic radius, in m

S : wetted section, in m^2

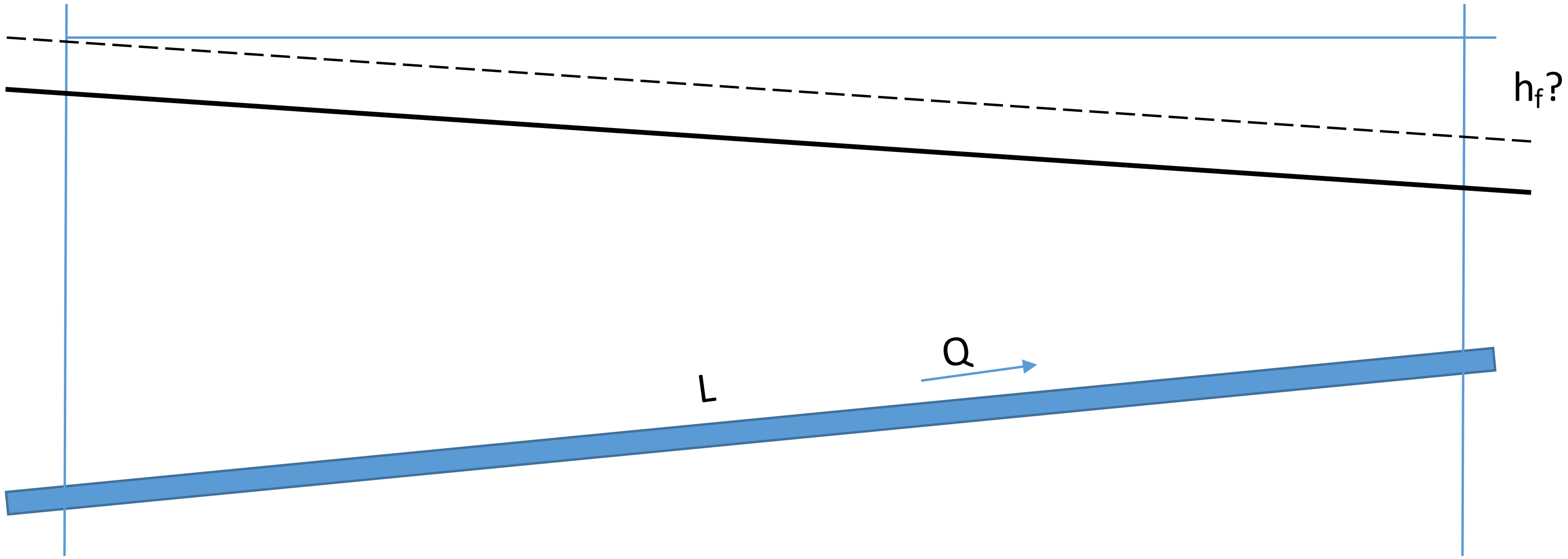
K_s or c_{GS} :Strickler roughness coefficient, en $m^{1/3}/s$

Indicative values for K_s ($m^{1/3}/s$)

Conduites en PE, PVC, cuivre, laiton	150
Fonte neuve, maçonnerie très lisse	80
Conduites en fonte ou en béton, très vieilles	70
Conduites en fonte en service	75
Acier revêtu	85
Fonte revêtue intérieurement neuve	110 à 125
Acier galvanisé	110 à 125

Example

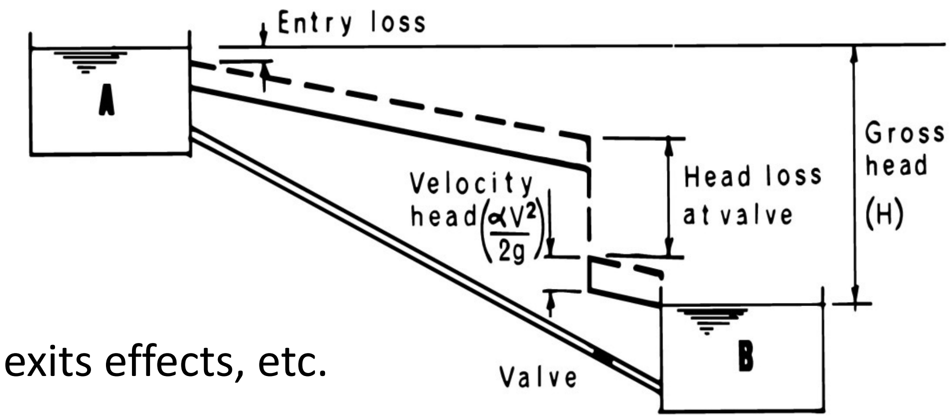
Compute the expected friction losses to pump water at a flowrate of 5 l/s over a 20 m long pipe with diameter d=6.5 cm and equivalent sand roughness k_s=0.26 mm.
What would the dissipation be in an hydraulically smooth pipe?



h_f=1.05 m

Localized energy losses

$$\Delta H_s = K \frac{v^2}{2g}$$



Local losses: e.g., due to bends, section changes, entrances, exits effects, etc.
K is often indicated as ξ

Difficulty : correct determination of K → tabulated values function of type of local geometry change

Correct way: to identify each single localized losses and calculated them via hydraulic theoretical/empriical relationship for the coefficient K, then sume up and solve the energy equation for D

Practical way: linear pressure losses are increased by 15 to 25% to take all singular pressure losses into account

Various (short) pipeline configurations

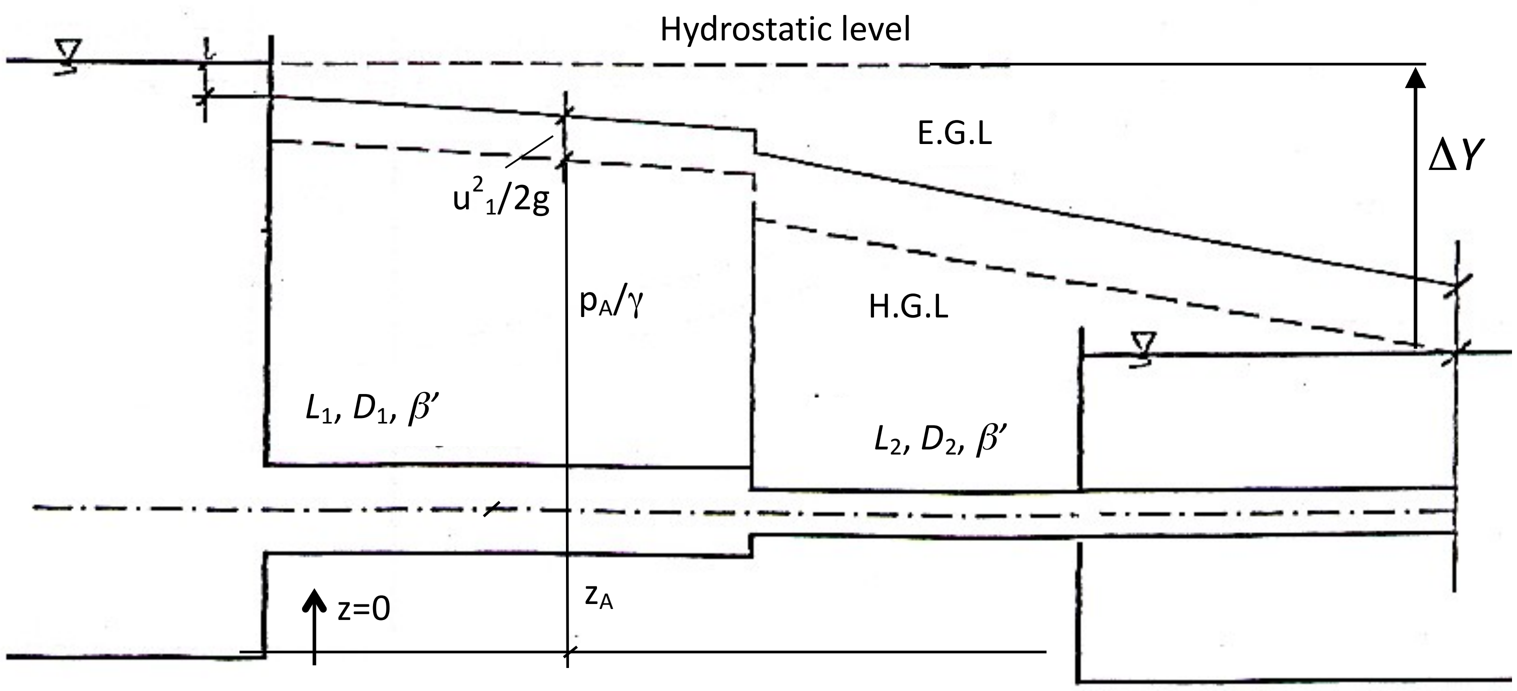


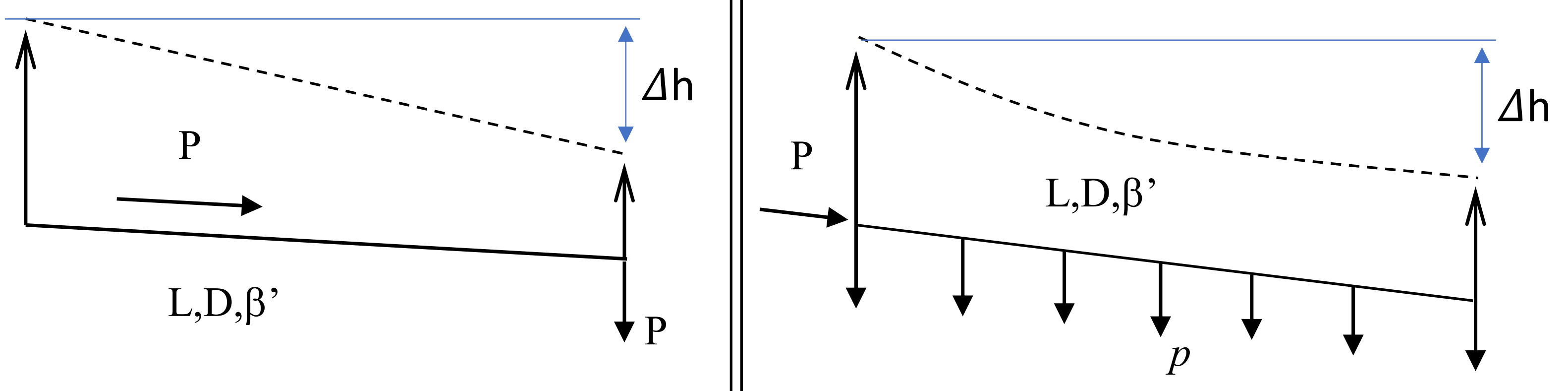
Figure 4

Energy balance eqaution $$\Delta Y = 0.5\frac{u_1^2}{2g} + \beta'\frac{Q^2}{d_1^{5.33}}L_1 + \xi\frac{u_1^2}{2g} + \beta'\frac{Q^2}{d_2^{5.33}}L_2 + \frac{u_2^2}{2g}$$

Distribution ramps

Pressure losses in ramps

Concentrated feed P | Distributed feed $P=pL$



$$\Delta h = \frac{\beta'}{D^{5.33}}\left(P^2 L\right)$$

← If D is constant then →

$$\Delta h = \frac{\beta'}{D^{5.33}}\left(\frac{1}{3}P^2 L\right)$$

Practical calculation of friction losses in ramps

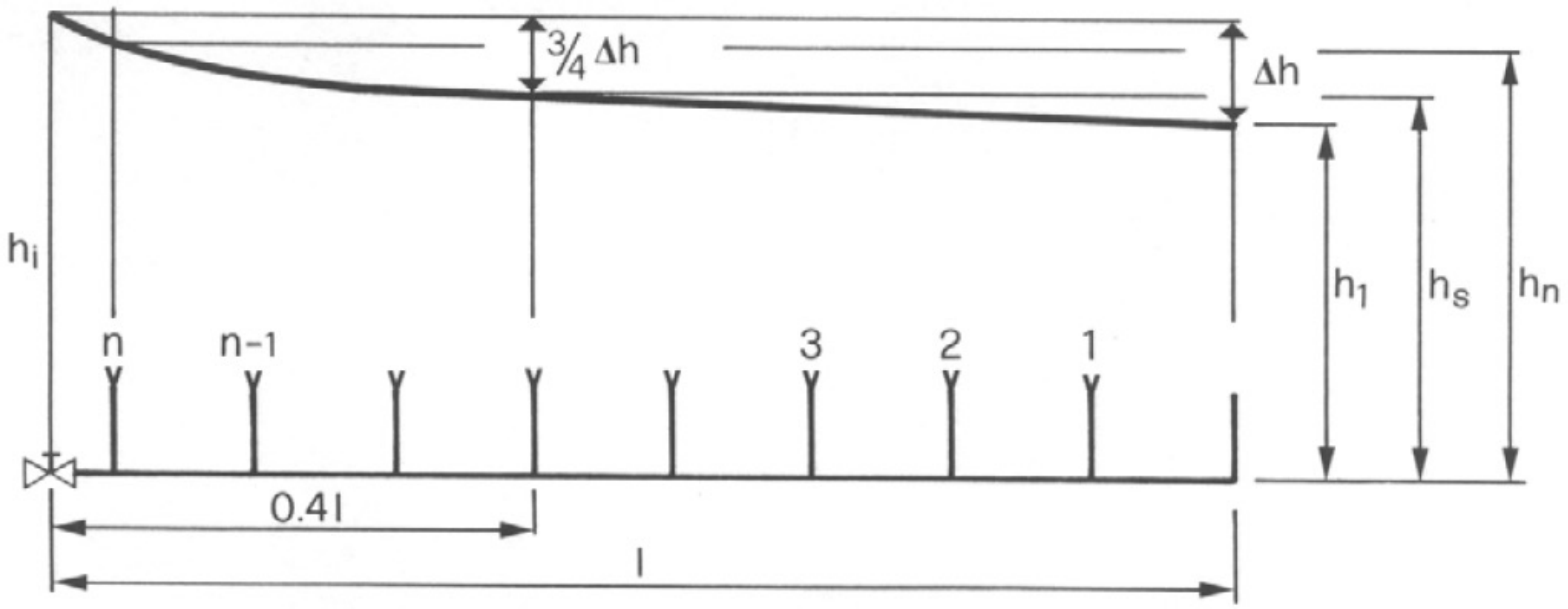


Fig. 18 Répartition de la pression hydraulique le long d'une rampe en service

Method of the effective length l_f

$$l_f = C\,e$$

l_f : fictitious length = length of a ramp such that, if the total inlet flow were to pass through it, there would be a head loss similar to that of the real ramp

e : spacing between sprinklers, in m

C : coefficient $$C = \frac{n(2n-1)}{6(n-1)}$$ n : total number of sprinklers mounted on the ramp

$$\Delta H = j\,l_f$$

ΔH : total headloss over the ramp

j : loss per unit length caused by the total flowrate entering the ramp

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Method of the fictitious headloss per unit length j_f

For aluminium and plastic pipes

$$j_f = j\,F$$

j_f : fictitious head loss

j : unit head loss for total flow rate

F: correction coefficient, a function of the number n of sprinklers on the ramp, the nature of the pipes and the position of the first sprinkler

$$\Delta H = j_f\,L$$

n	Rampe en plastique F_1 (a)	Rampe en plastique F_2 (b)	Rampe en plastique F_3 (c)	Rampe en aluminium F_1 (a)	Rampe en aluminium F_2 (b)	Rampe en aluminium F_3 (c)
5	0.469	0.337	0.410	0.457	0.321	0.396
10	0.415	0.350	0.384	0.402	0.336	0.371
12	0.406	0.352	0.381	0.393	0.338	0.367
15	0.398	0.355	0.377	0.385	0.341	0.363
20	0.389	0.357	0.373	0.376	0.343	0.360
25	0.384	0.358	0.371	0.371	0.345	0.358
30	0.381	0.359	0.370	0.368	0.346	0.357
40	0.376	0.360	0.368	0.363	0.347	0.355
50	0.374	0.361	0.367	0.361	0.348	0.354
100	0.369	0.362	0.366	0.356	0.349	0.352
200	0.366	0.363	0.365	0.353	0.350	0.352

a) lorsque le premier asperseur est à une distance e de la conduite d'eau
b) lorsque le premier asperseur est à proximité immédiate de la conduite
c) lorsque le premier asperseur est à une distance e/2 de la conduite

(e: spacing between the sprinklers)

ΔH : perte de charge totale dans la rampe

L : longueur réelle de la rampe

Christiansen's rule (rule of the 20 %)

The difference in pressure between the various sprinklers should not exceed 20%

Such a difference results in variations in flow of less than 10%.

$$Q = C\,S\,\sqrt{2gH} = C^{'}\sqrt{H}$$

If H augments of 20 % : H' = H + 0.2 H = 1.2 H and :

$$Q^{'} = C^{'}\sqrt{1.2H} = 1.1\,C^{'}\sqrt{H} \;\rightarrow\; \frac{Q^{'}}{Q} = \frac{1.1\,C^{'}\sqrt{H}}{C^{'}\sqrt{H}} = 1.1$$

Results in variation of flowrate of about 10 %