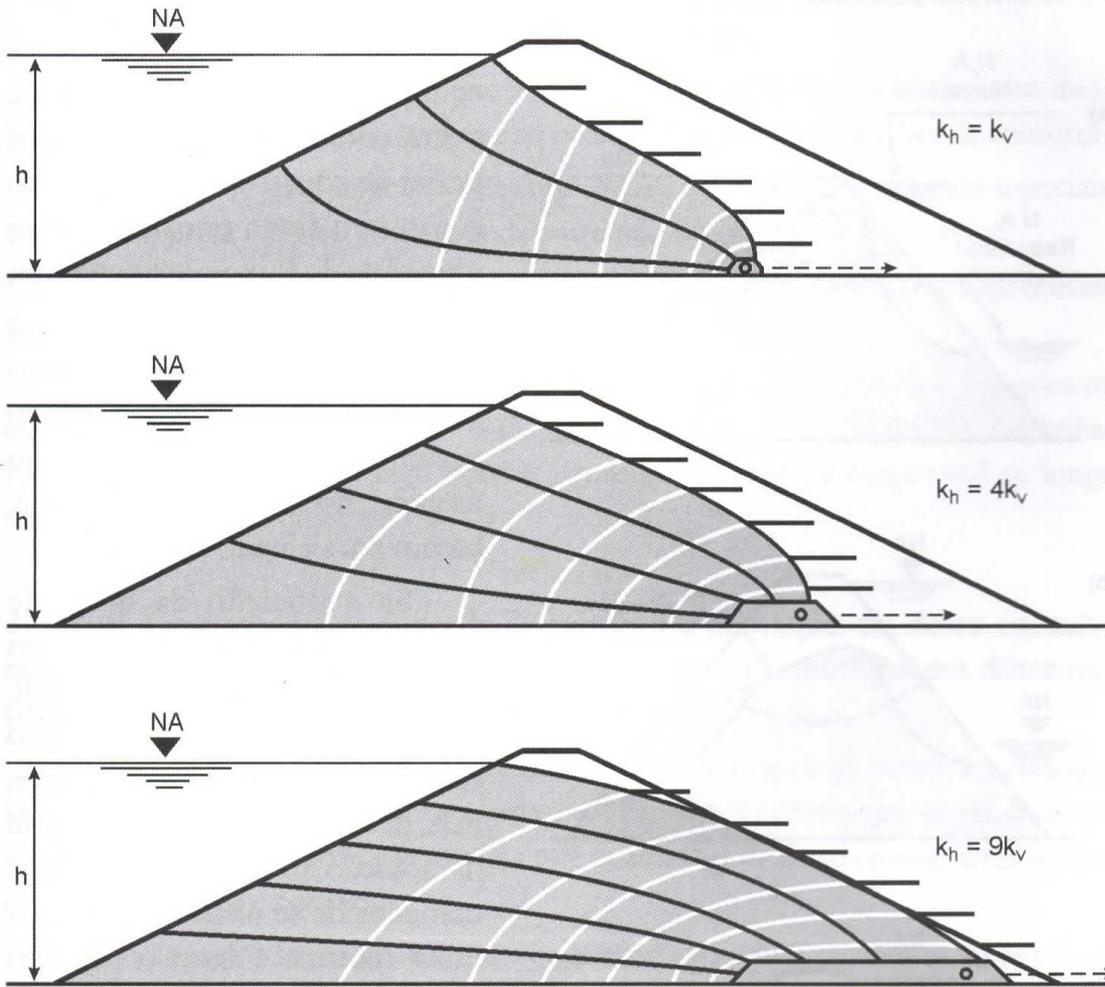


# APLICAÇÕES DOS CONCEITOS DE PERCOLAÇÃO

Maria Eugenia Gimenez Boscov

# Meio anisotrópico

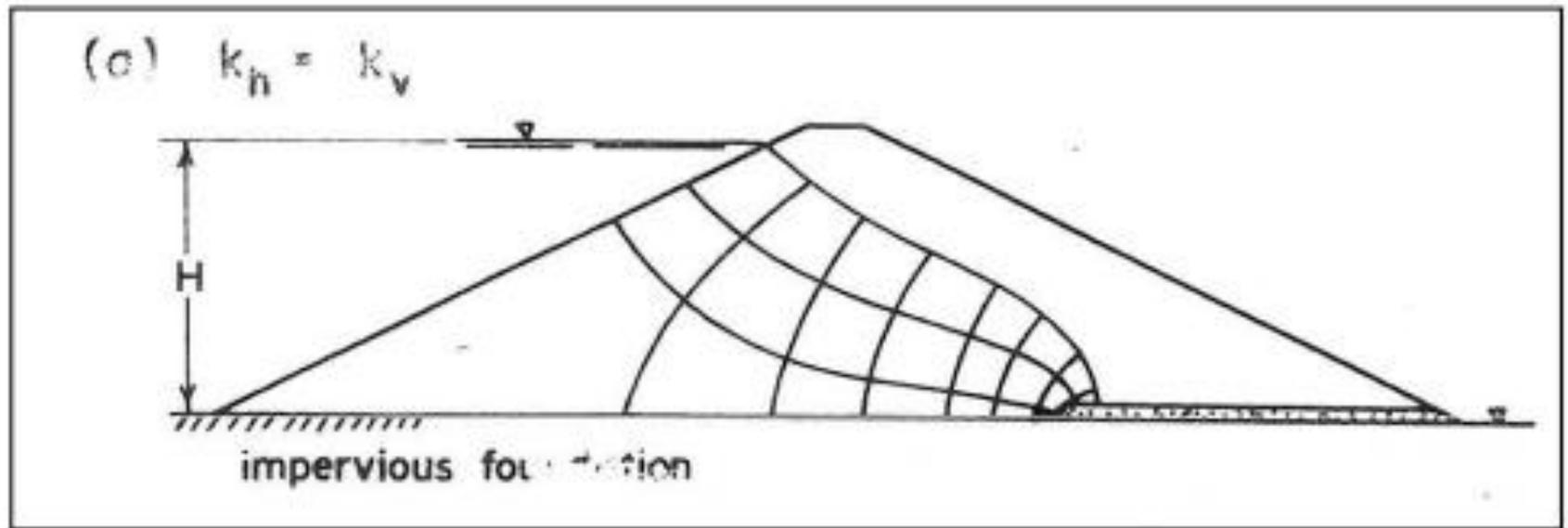




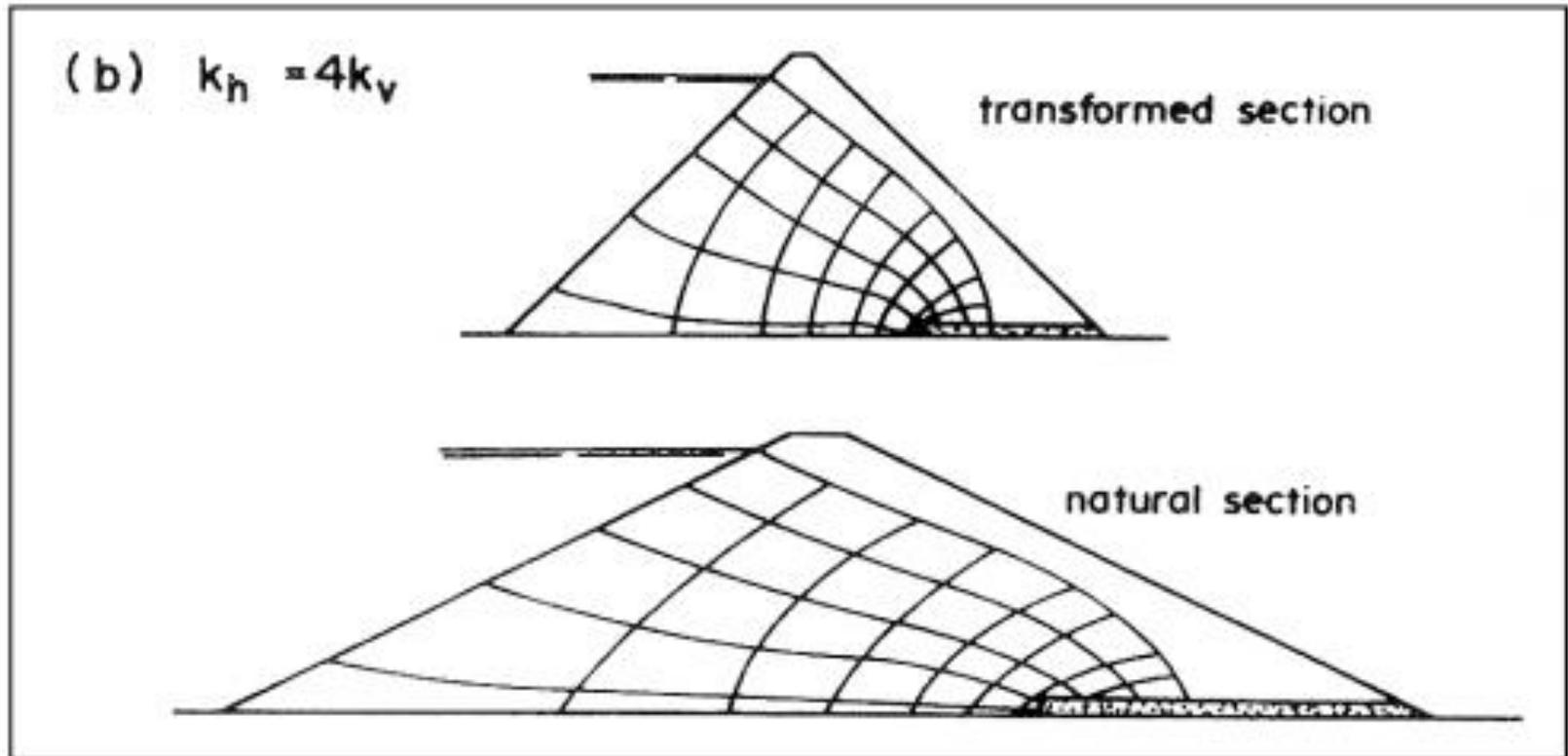
**Fig. 1.20**

**Exemplos de redes de fluxo bidimensionais, não confinadas, em meios anisotrópicos (Cedergren, 1967)**

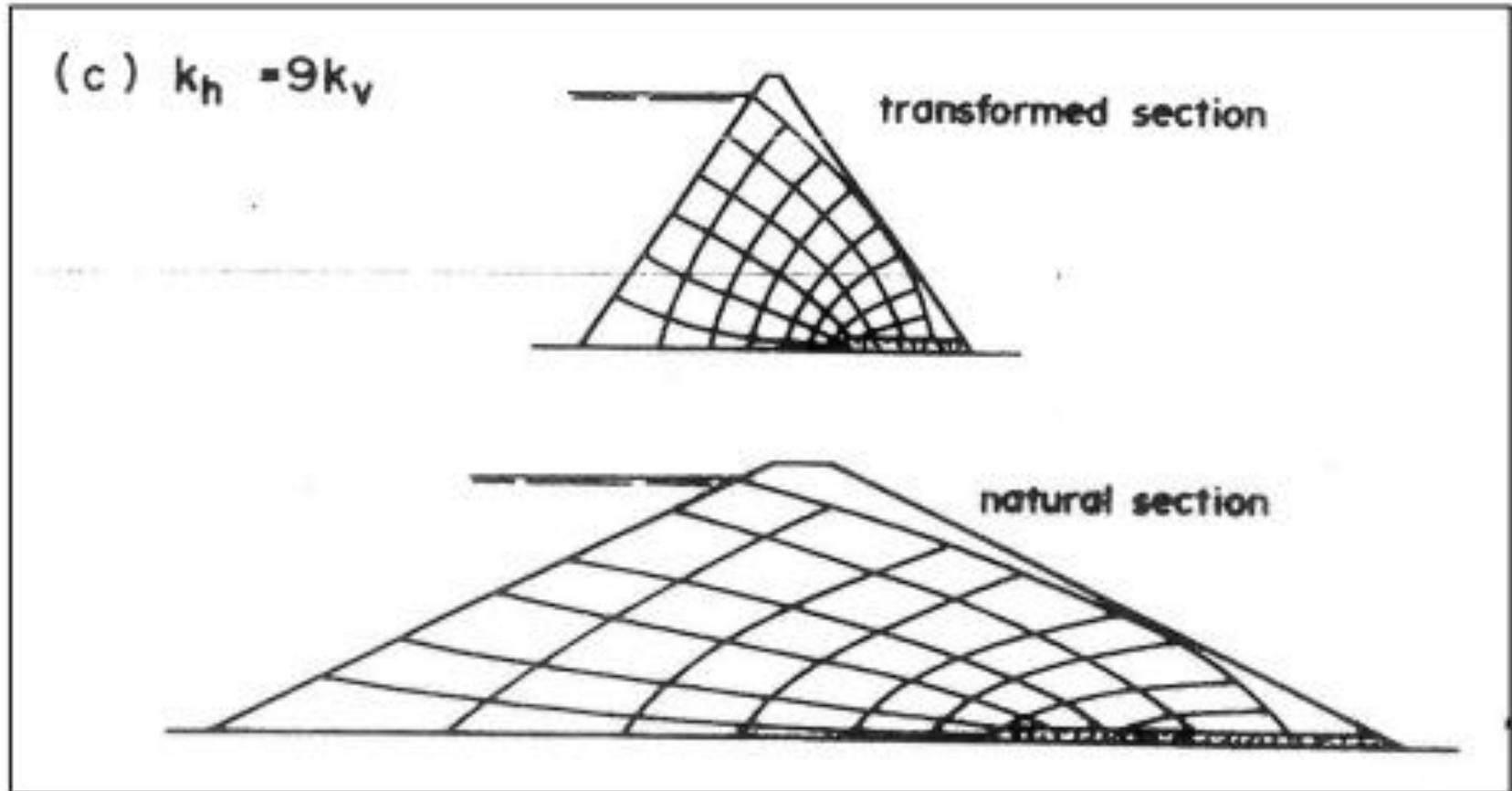
# Influência da Anisotropia na Rede de Fluxo Através da Barragem

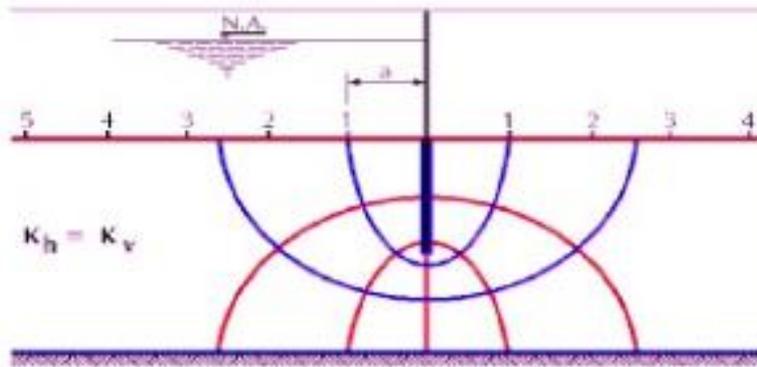


# Influência da Anisotropia na Rede de Fluxo Através da Barragem

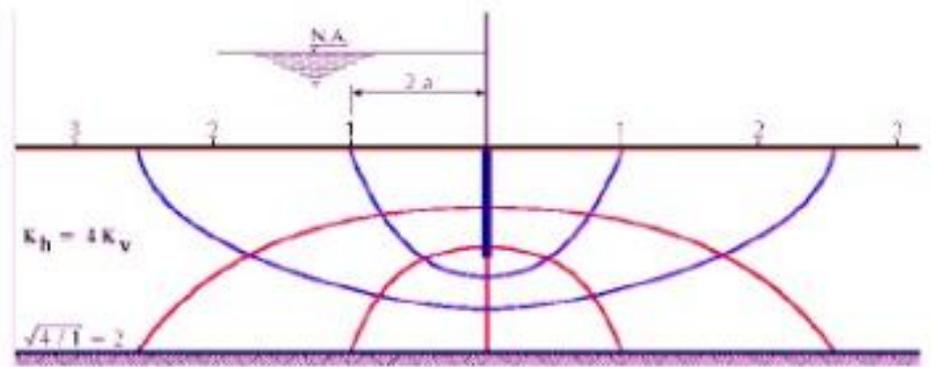


# Influência da anisotropia na rede de fluxo através da barragem

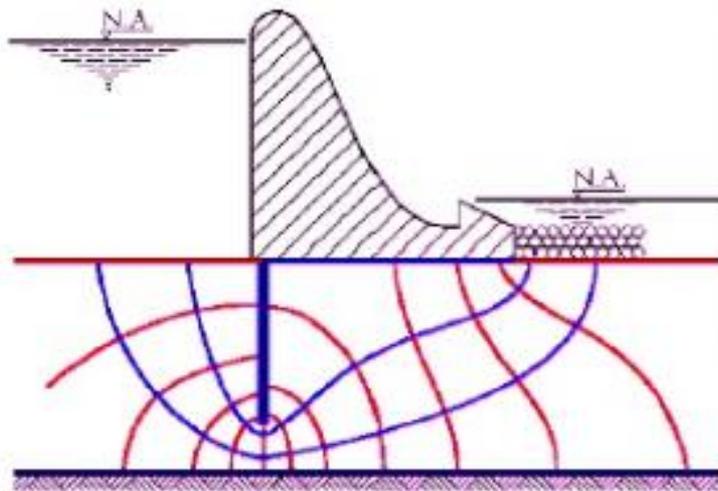




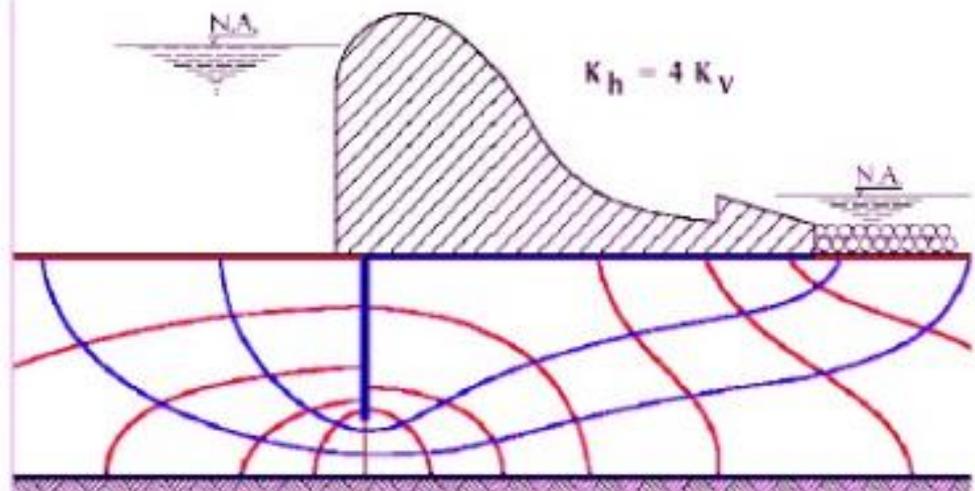
(a) seção transformada



(b) Seção real

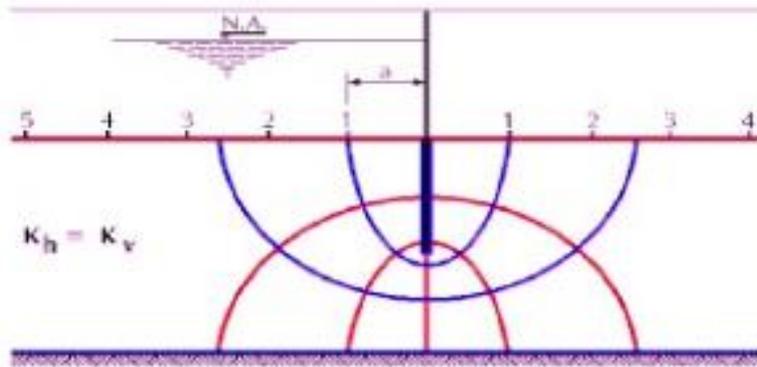


(a) seção transformada

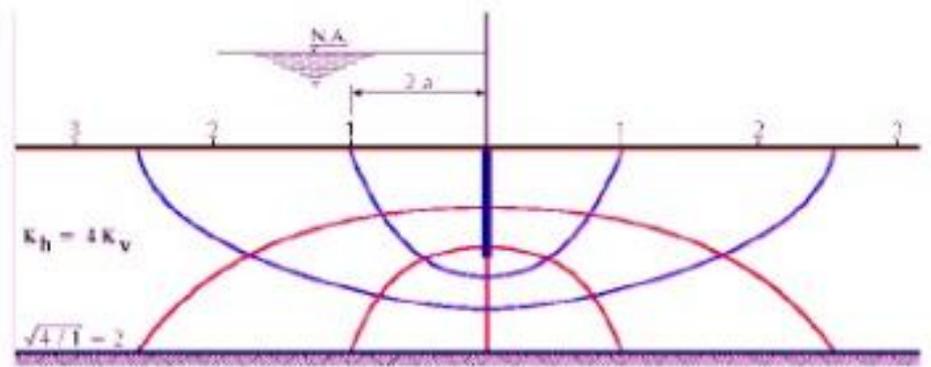


(b) Seção real

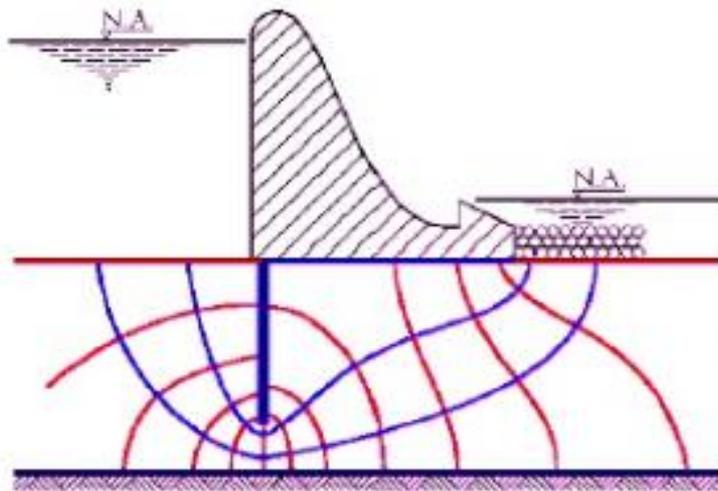
**Figura 3.20 – Exemplos de rede de fluxo em meios anisotrópicos. Modificado de Stancati (1984).**



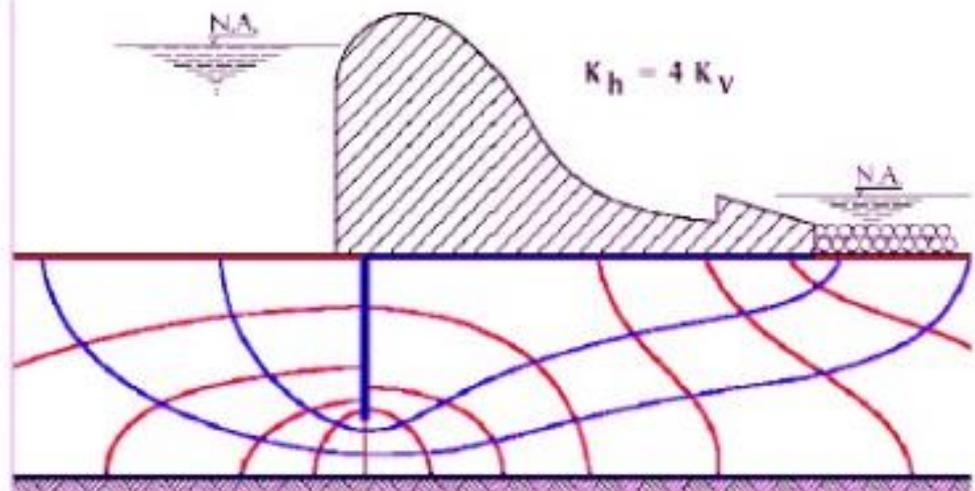
(a) seção transformada



(b) Seção real



(a) seção transformada

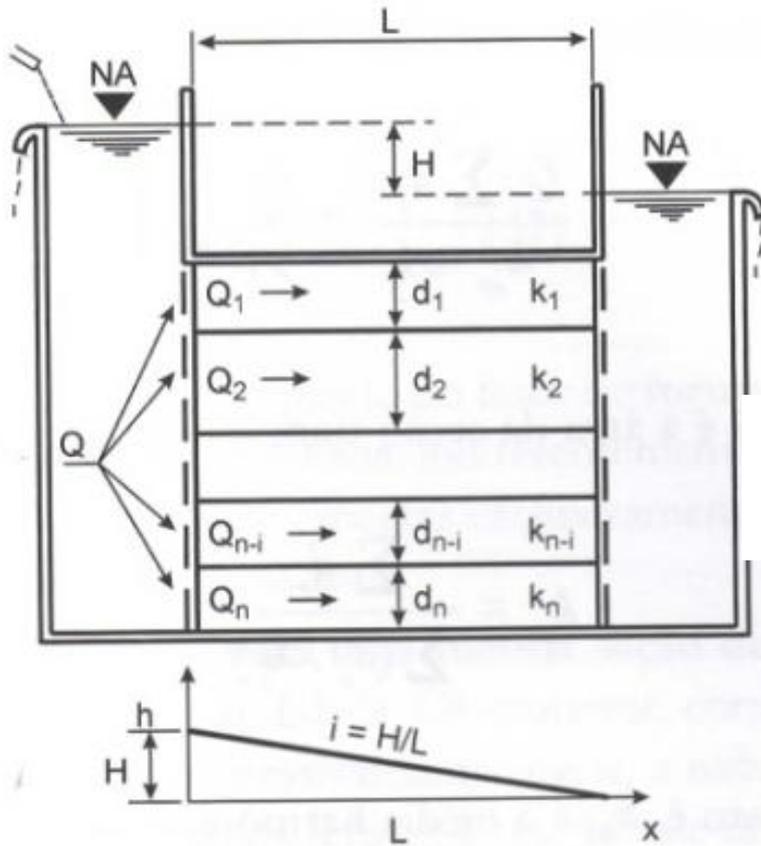


(b) Seção real

**Figura 3.20 – Exemplos de rede de fluxo em meios anisotrópicos. Modificado de Stancati (1984).**

# Meio heterogêneo



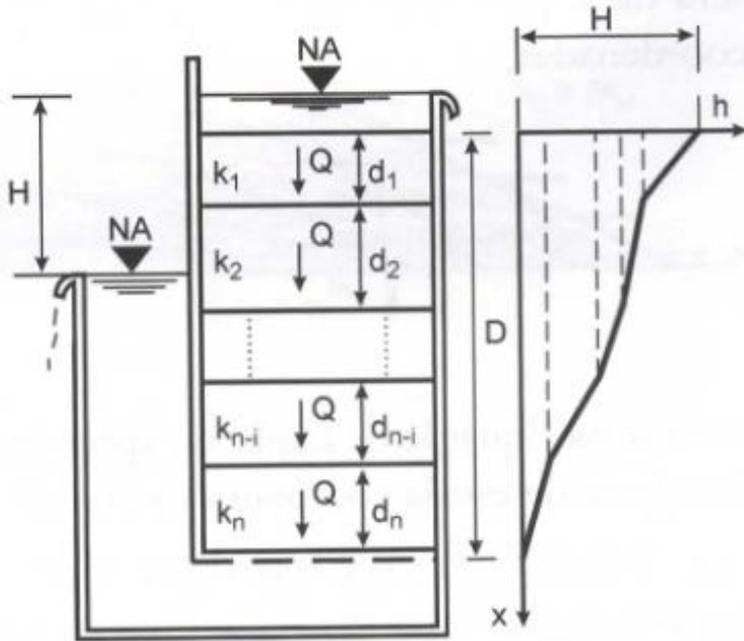


$$Q = \sum Q_i = \sum \left( k_i \cdot \frac{H}{L} \cdot d_i \right) = \left( \frac{H}{L} \right) \cdot \sum (k_i \cdot d_i)$$

$$Q = k_m \cdot \left( \frac{H}{L} \right) \cdot \sum d_i$$

$$k_m = \frac{\sum (k_i \cdot d_i)}{\sum d_i}$$

(Massad, 2010)



$$H = \sum b_i$$

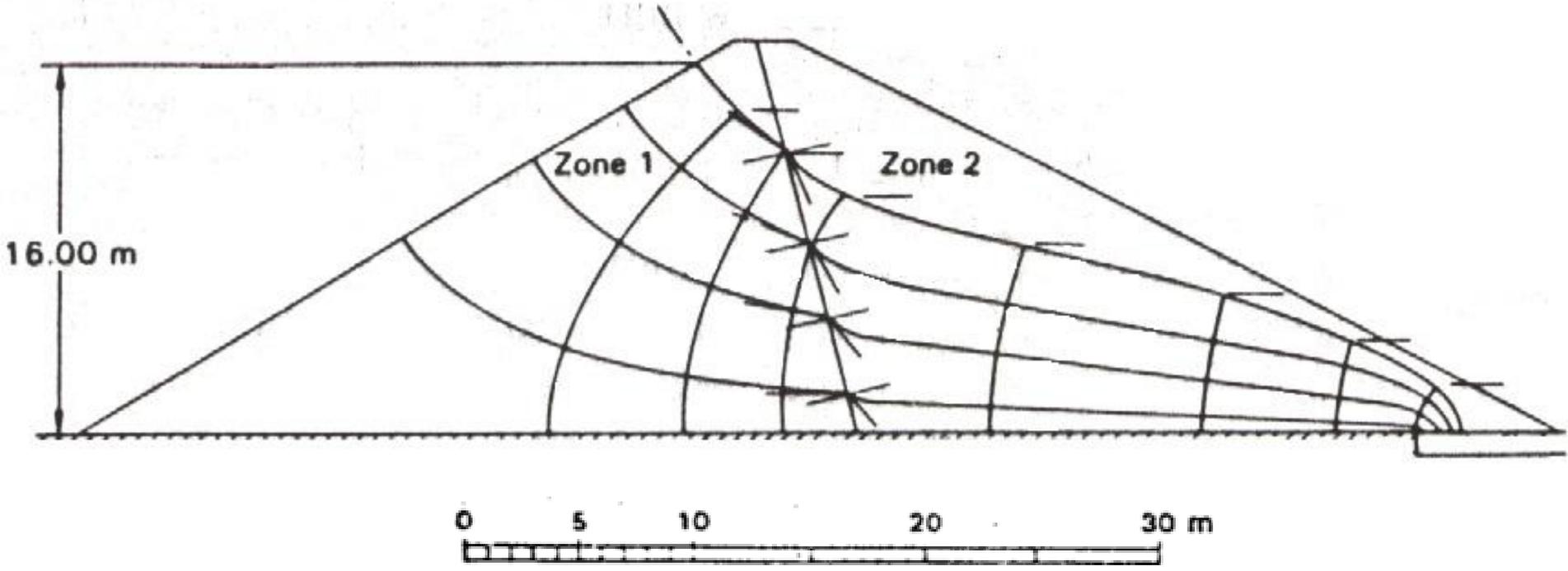
$$\frac{b_i}{d_i} = \frac{Q}{k_i \cdot A}$$

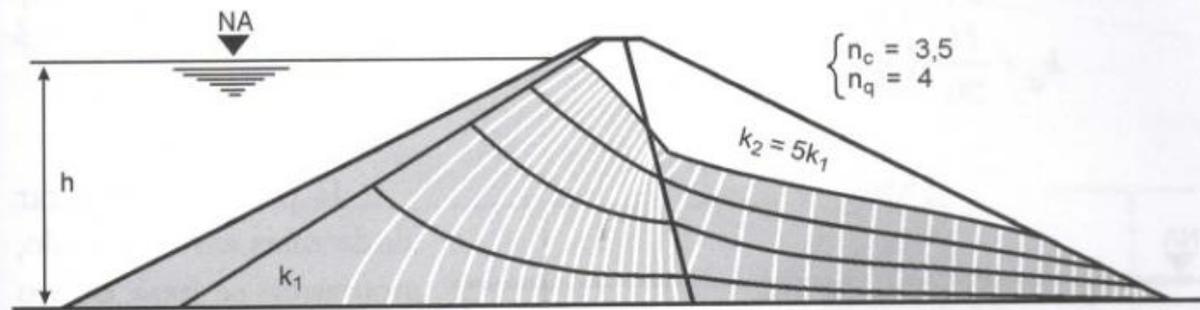
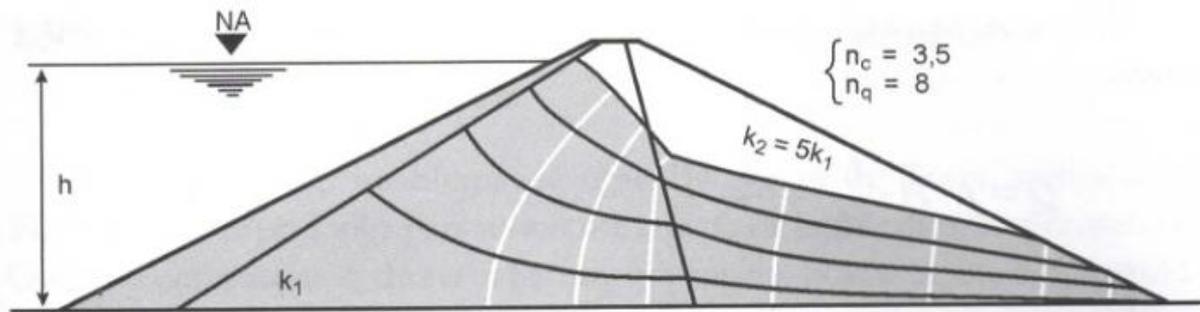
$$\frac{Q \sum d_i}{k_m A} = \frac{Q}{A} \sum \frac{d_i}{k_i}$$

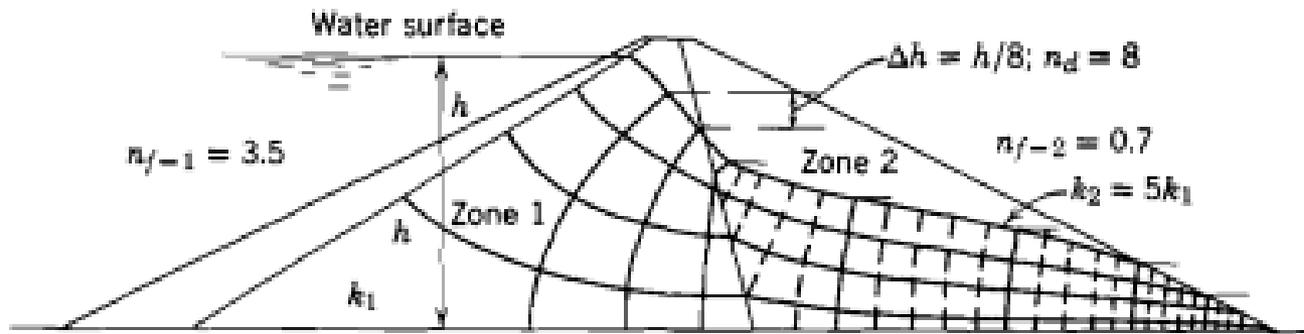
$$k_m = \frac{\sum d_i}{\sum \frac{d_i}{k_i}}$$

(Massad, 2010)

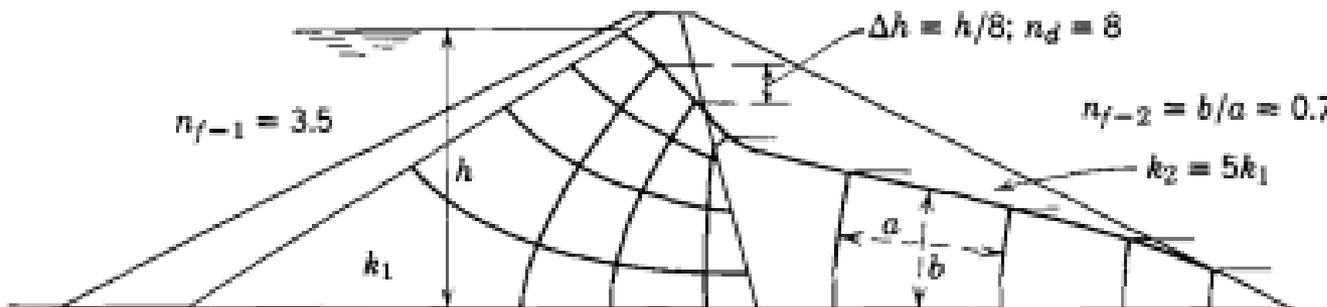
# Influência da heterogeneidade na rede de fluxo através da barragem



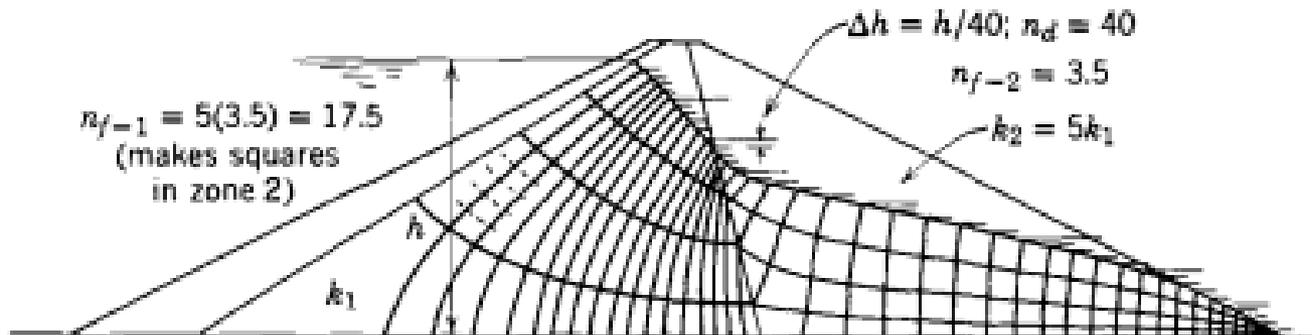




(a)



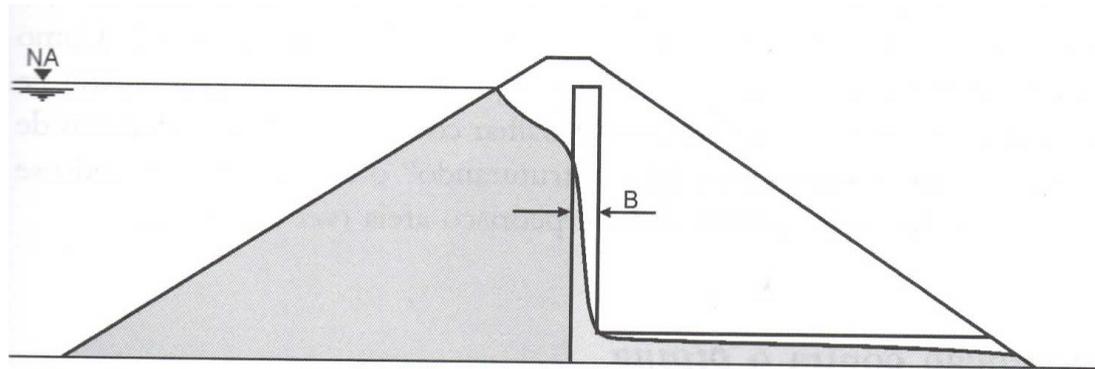
(b)



(c)

Três formas  
para uma só  
rede de fluxo

# Filtro vertical

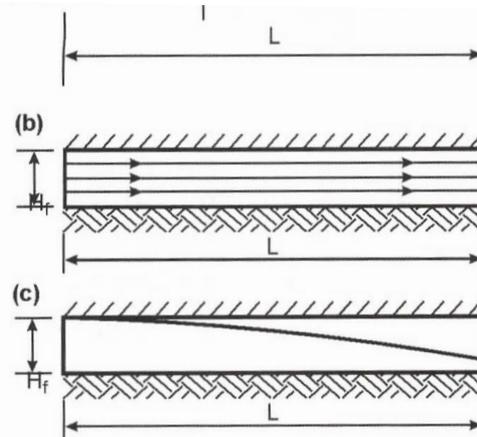
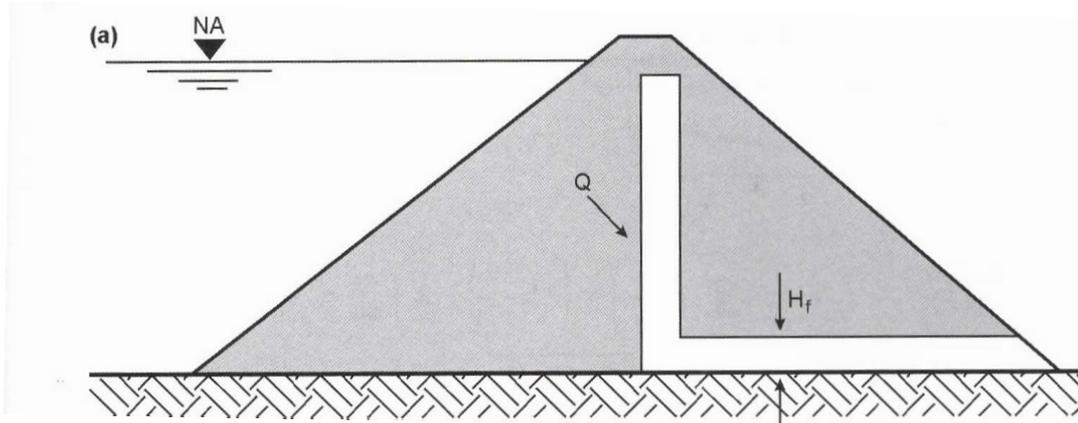


$$Q_{\text{maciço}} = k_{fv} iA = k_{fv} \cdot 1 \cdot (B \cdot 1) = k_{fv} B$$

$$b = \frac{Q_{\text{maciço}}}{k_{fv}}$$

(Massad, 2010)

# Filtro horizontal



(Massad, 2010)

Hipótese: filtro trabalha em carga, utilizando toda a sua seção para o fluxo d'água

$$Q = k_f \cdot \frac{H_f}{r} \cdot H_f = k_f \cdot \frac{H_f^2}{L}$$

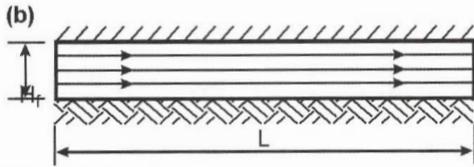
$$H_f^{real} > \sqrt{\frac{Q \cdot L}{k_f}}$$

Hipótese: filtro trabalha livremente, com a existência de uma linha freática

$$Q = \frac{k \cdot (b_1^2 - b_2^2)}{2 \cdot L}$$

# Filtro horizontal

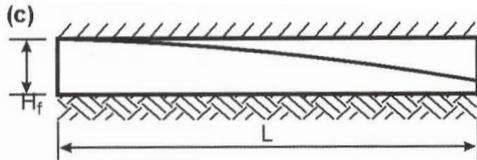
- Hipótese: filtro trabalha em carga, utilizando toda a seção para o fluxo d'água



$$Q = k_f \cdot \frac{H_f}{L} \cdot H_f = k_f \cdot \frac{H_f^2}{L}$$

$$H_f^{real} > \sqrt{\frac{Q \cdot L}{k_f}}$$

- Hipótese: filtro trabalha livremente, com a existência de uma linha freática

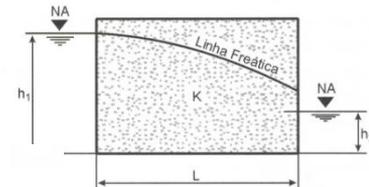


Equação de Dupuit

$$Q = \frac{k \cdot (b_1^2 - b_2^2)}{2 \cdot L}$$

$$Q = \frac{k_f \cdot H_f^2}{2 \cdot L}$$

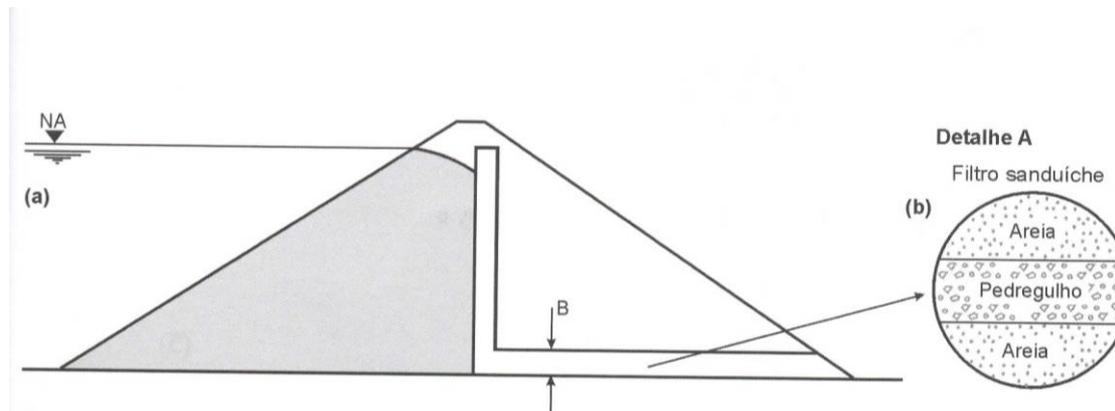
$$H_f^{real} < \sqrt{\frac{2 \cdot Q \cdot L}{k_f}}$$



- Portanto:

$$\sqrt{\frac{Q \cdot L}{k_f}} < H_f^{real} < \sqrt{\frac{2 \cdot Q \cdot L}{k_f}}$$

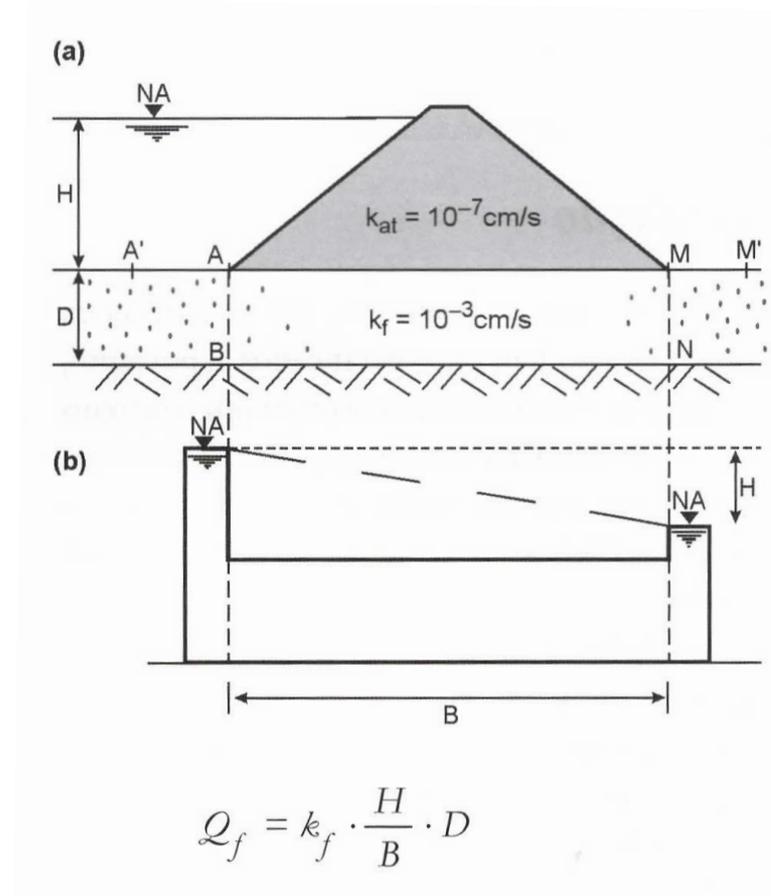
# Filtro horizontal



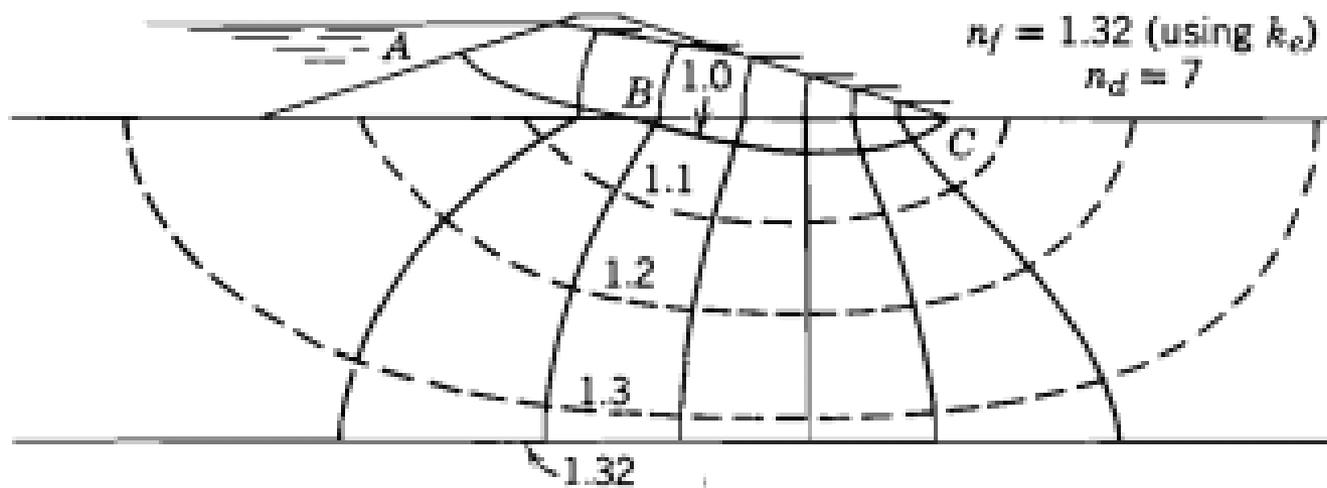
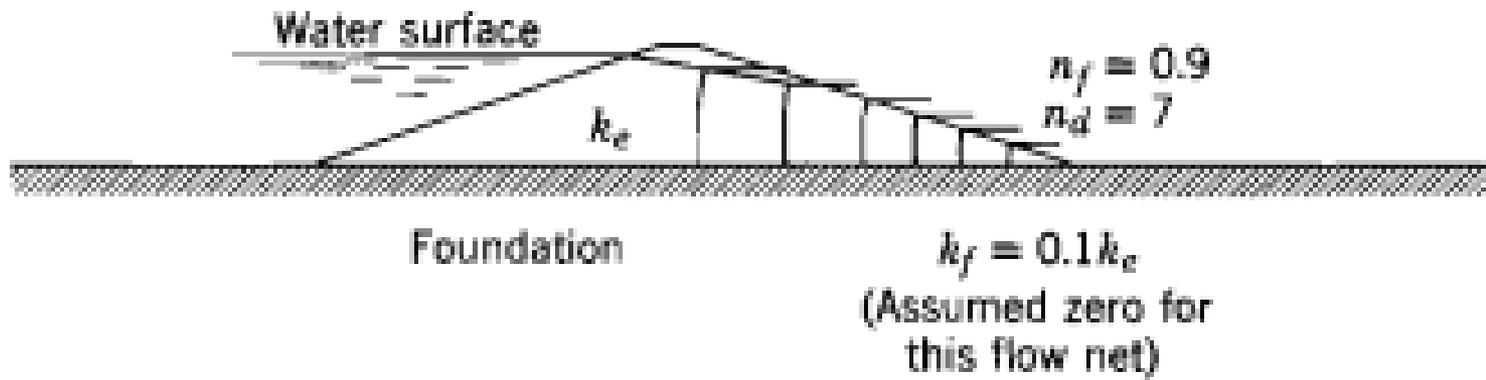
$$k_m = \frac{\sum (k_i d_i)}{\sum d_i}$$

$$Q = k_m \cdot \left(\frac{H}{L}\right) \cdot \sum d_i$$

# Perda de água pela fundação



$$Q_f = k_f \frac{H}{B + 0,88D} D \quad (\text{Dachler})$$



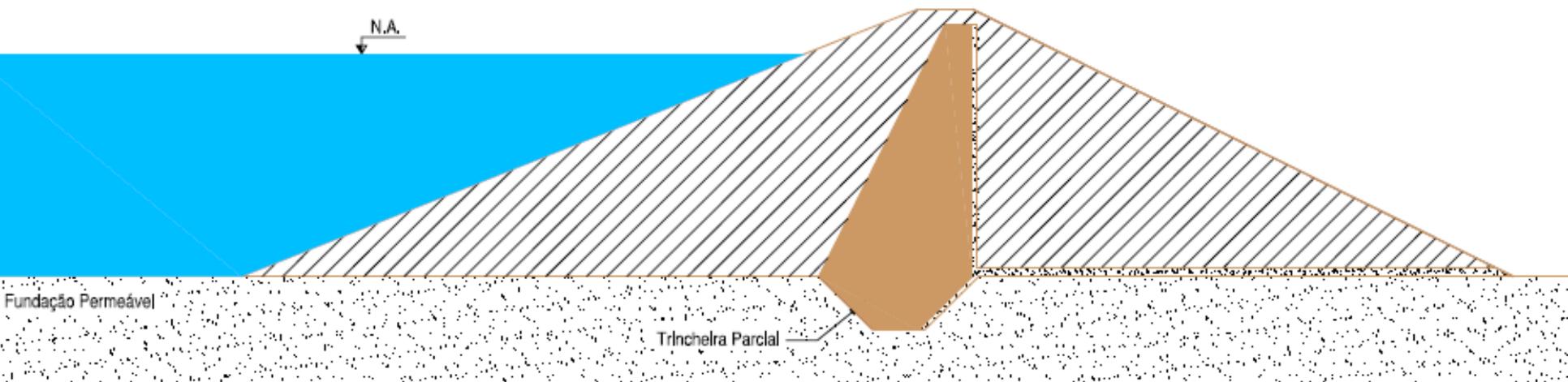
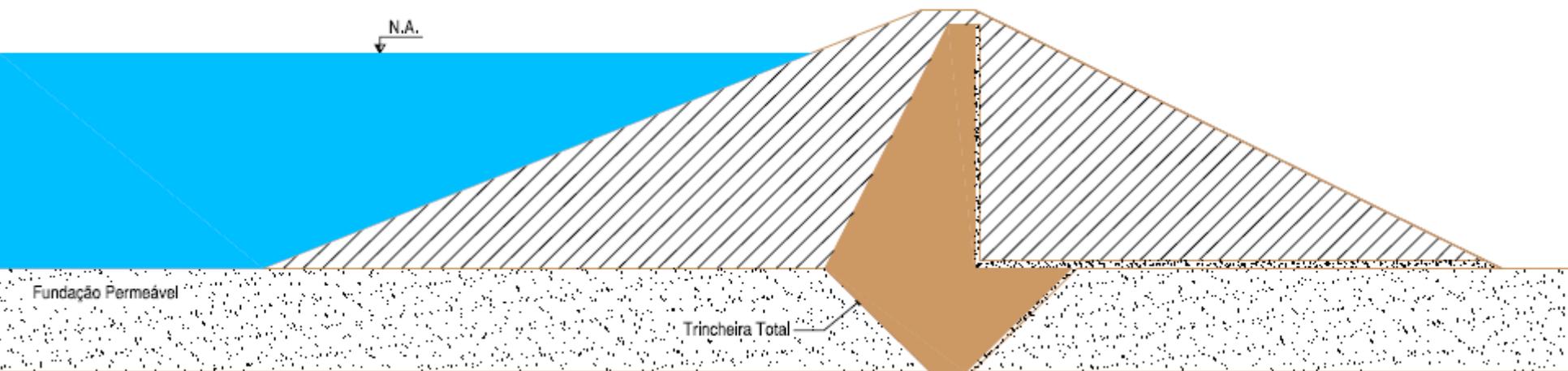
# Eficiência do tratamento

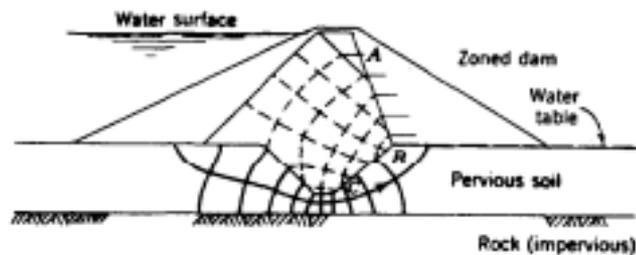
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$$E = 1 - \frac{Q_f}{Q_{f0}}$$

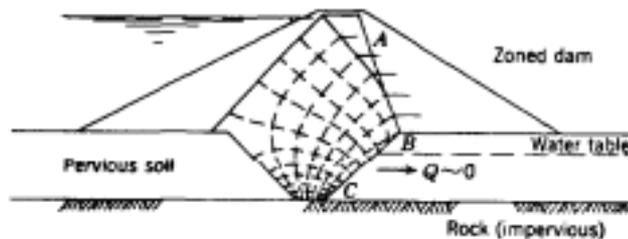
# Trincheiras de vedação (*cut off*)



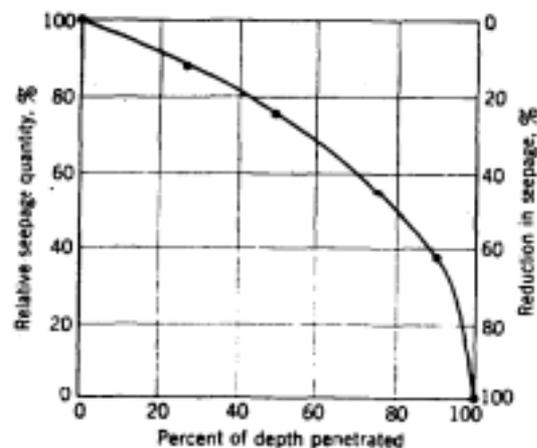




a. Partial cutoff

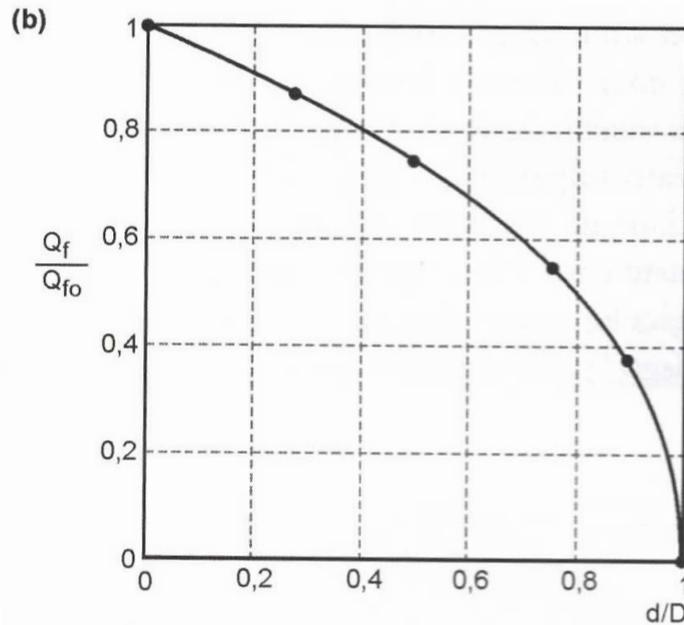
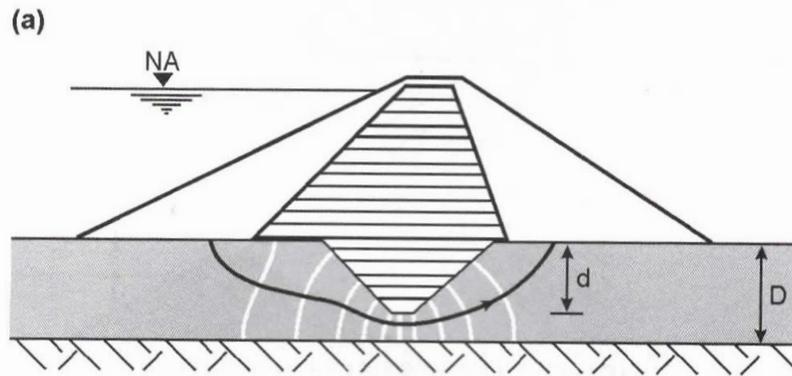


b. Complete cutoff



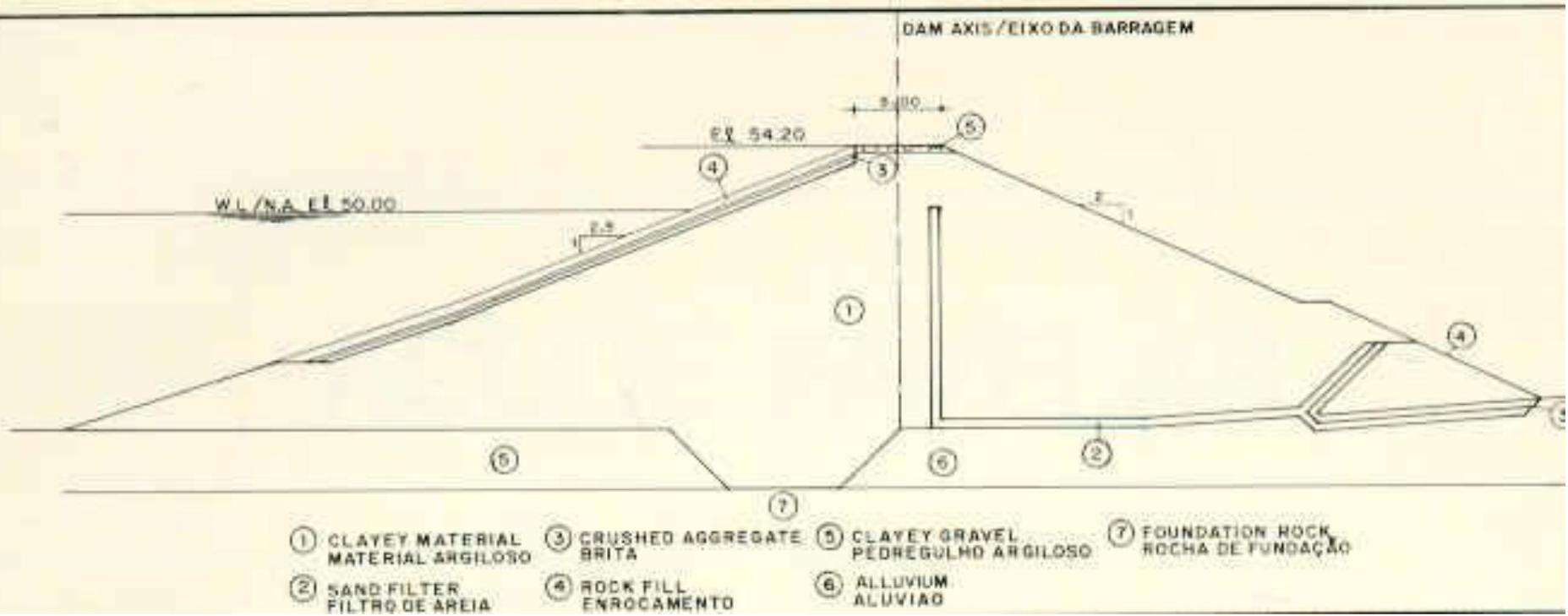
c. Relationship between quantity of seepage and depth of penetration of partial cutoff

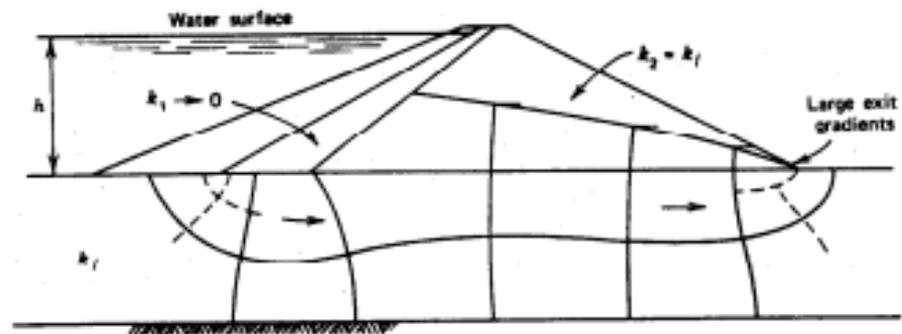
Figure 9-3. Efficiency of a compacted backfill trench partial cutoff in reducing the quantity of underseepage (courtesy of John Wiley and Sons<sup>155</sup>)



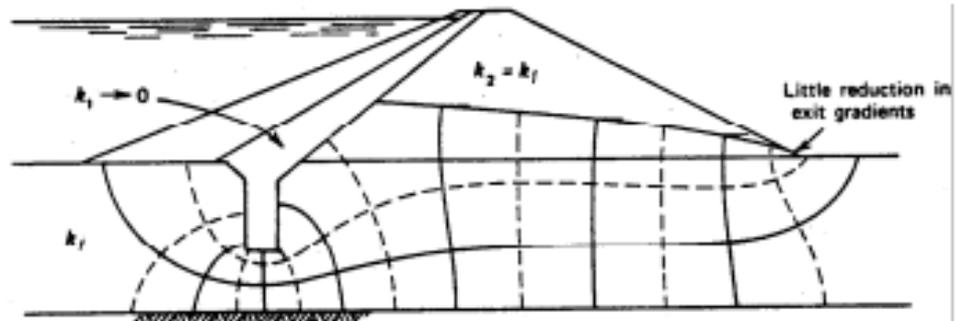
**Fig. 8.2**

**(a) Barragem de terra com trincheira de vedação ou cut off;**  
**(b) variação das perdas d'água em função da penetração do cut off (Cedergren, 1967)**

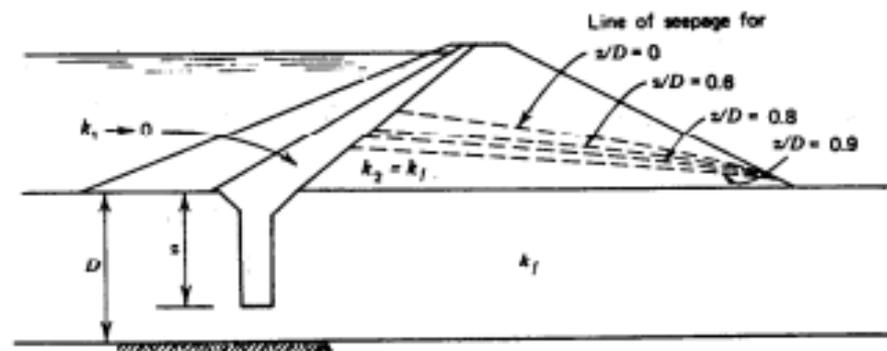




a. Flow net for no cutoff

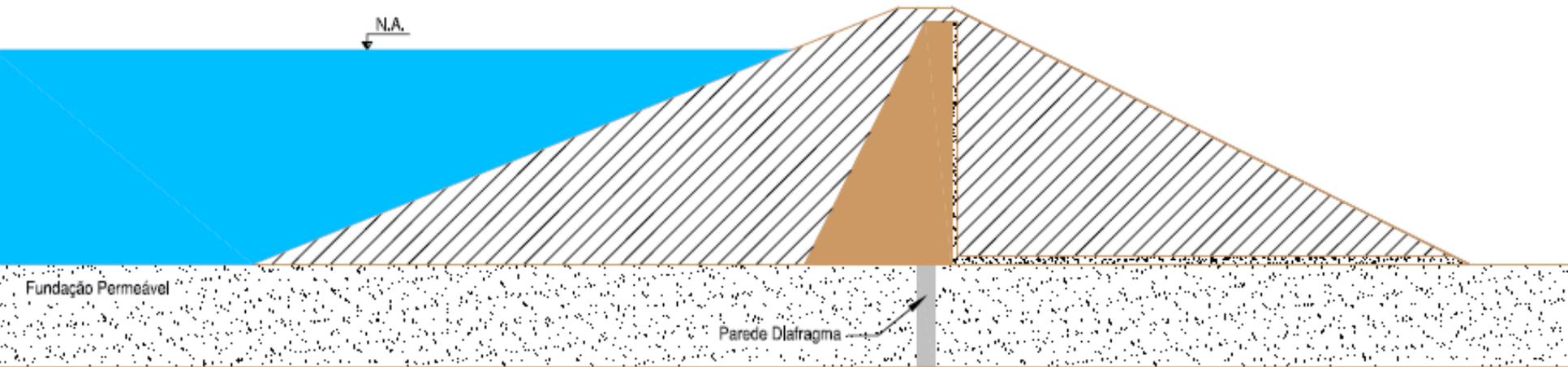


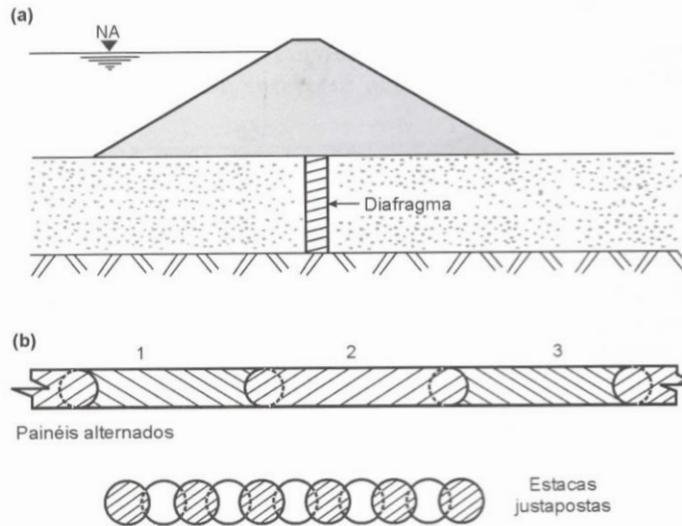
b. Flow net for partial cutoff



c. Position of line of seepage for various values of penetration

# Parede diafragma





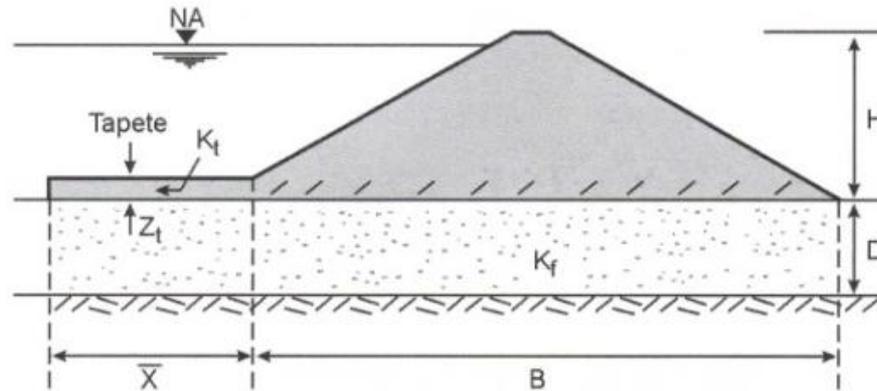
**Fig. 8.5**  
**Diafragmas para**  
**interceptar o fluxo de**  
**água pelas fundações**

$$k_m = \frac{B}{\frac{B-b}{k_f} + \frac{b}{k_d}}$$

$$Q_f = k_m \frac{H}{B} D$$

$$Q_f = \frac{k_f H}{0,88D + B + b \left( \frac{k_f}{k_d} - 1 \right)} D$$

# Tapete impermeável de montante



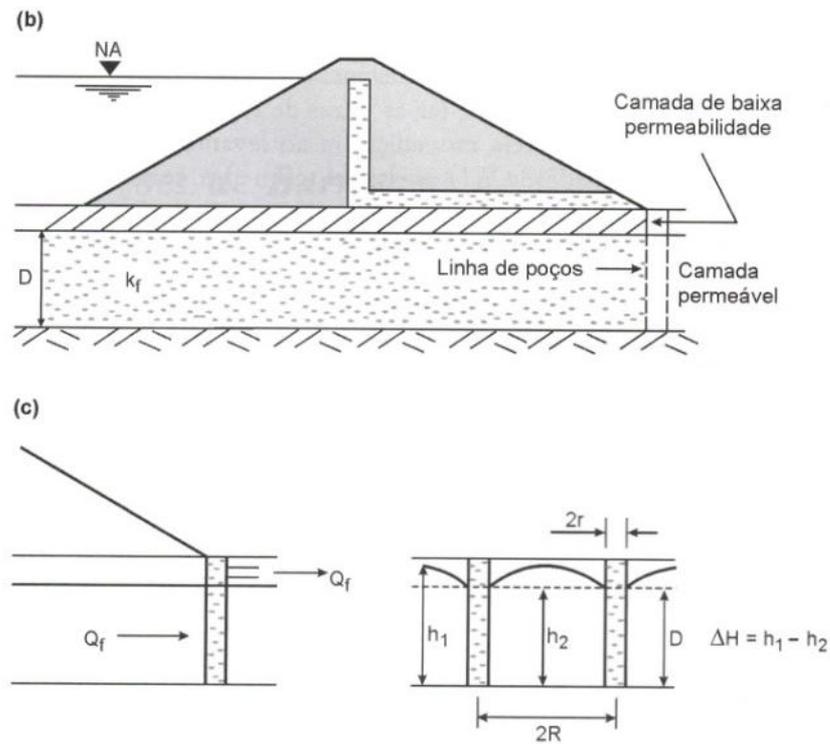
$$Q_f = k_f \frac{H}{0,88D + B + x_r} D$$

$x_r$  = comprimento do tapete se ele for totalmente impermeável

Se não for totalmente impermeável,  $x_r$  é o comprimento equivalente impermeável

$$x_r = 0,63\bar{x} \quad \bar{x} = \frac{\sqrt{2}}{a} \quad a = \sqrt{\frac{k_t}{k_f z_t z_f}}$$

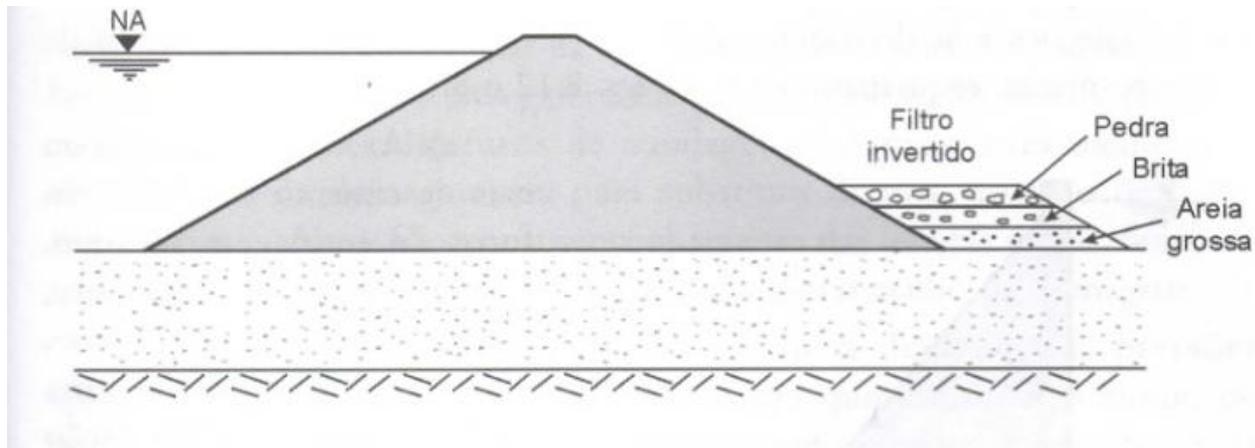
# Poços de alívio



**Fig. 8.9**

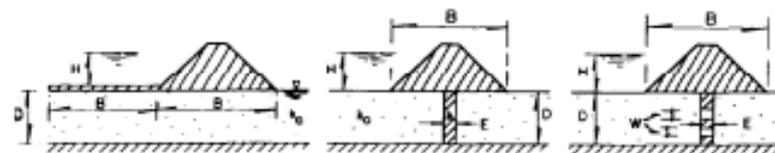
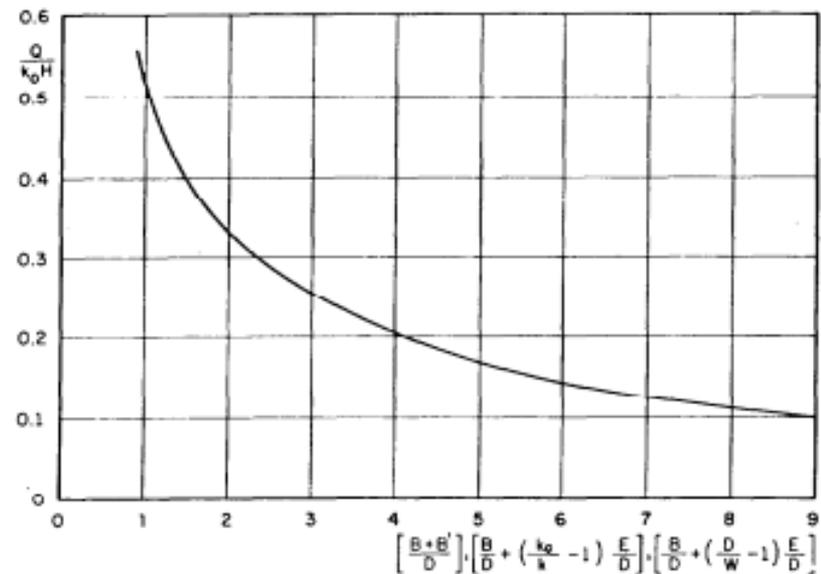
**Poços de alívio para o controle da saída d'água, a jusante**

# Filtro invertido



**Fig. 8.10**

***Filtro invertido  
para controle de  
gradientes de  
saída.***



Impervious upstream  
blanket

Compacted backfill trench or  
concrete wall or slurry  
steel sheetpiling trench

Figure 9-5. Rate of underseepage loss for impervious upstream blanket, compacted backfill trench or slurry trench, and concrete wall or steel sheetpiling with defects (courtesy of American Society of Civil

Engineers<sup>218</sup>)

$$\frac{Q}{k_0 \cdot H} = \frac{1}{0,88 + \frac{B}{D} + \left( \frac{D}{W} - 1 \right) \cdot \frac{E}{D}}$$

Marsal et al., 1971

---

parede diafragma preenchida com solo argiloso, a partir da determinação da largura da base do maciço da barragem ( $B$ ), da largura do diafragma ( $L$ ) da espessura do estrato permeável da fundação ( $D$ ) e dos coeficientes de permeabilidade do maciço da fundação ( $K$ ) e do material de preenchimento do diafragma ( $K_1$ ). A eficácia é determinada a partir da Equação 13.

$$E(\%) = \frac{100 \left[ \frac{L \times \left( \frac{K}{K_1} - 1 \right)}{D} \right]}{0,88 + \frac{B}{D} + L \times \left( \frac{K}{K_1} - 1 \right) \cdot \frac{1}{D}}$$

$$\frac{Q}{k_0 \cdot H} = \frac{1}{0,88 + \frac{B + B'}{D}}$$

Equação 14

Onde,

$Q$  = vazão percolada através da fundação ( $L^3.T^{-1}$ );

$k_0$  = permeabilidade do estrato permeável da fundação ( $L.T^{-1}$ );

$H$  = carga hidráulica total do reservatório (L);

$B$  = largura da base do maciço da barragem (L);

$B'$  = comprimento do tapete de montante (L); e

$D$  = espessura da camada permeável da fundação (L).

Para o caso de barragens com trincheiras de vedação ou cortinas de injeção, Marsal et al. (1971) apresentaram a Equação 15 derivada de Ambraseys (1963).

$$\frac{Q}{k_0 \cdot H} = \frac{1}{0,88 + \frac{B}{D} + \left(\frac{k_0}{k} - 1\right) \cdot \frac{E}{D}}$$

Equação 15

Onde

$k$  = permeabilidade da cortina de injeção ou do solo compactado da trincheira de vedação ( $L.T^{-1}$ ); e

$E$  = espessura da cortina ou da trincheira.

As variáveis comuns à Equação 14 têm os mesmos significados.