

PEF 3502

Estruturas subterrâneas

Estruturas internas
Conduitos e galerias

Conduitos - conceitos gerais (Watkins)

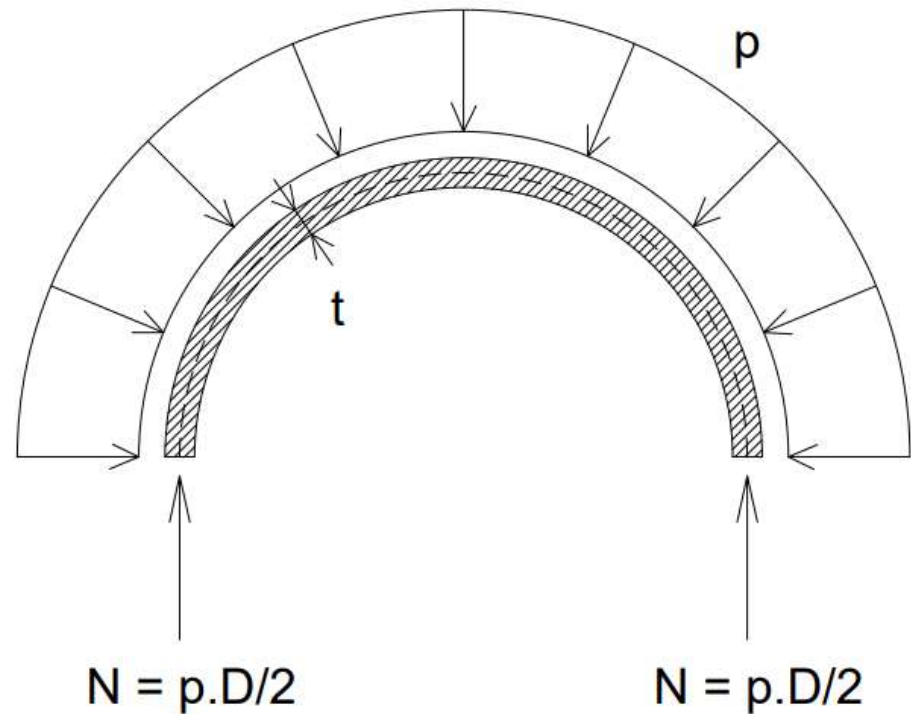
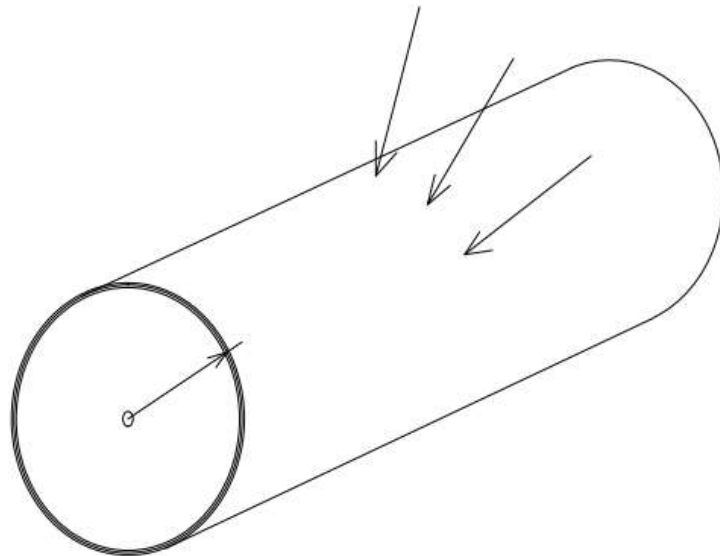
- Solo
 - Não compressível: caso específico, visto de forma simplificada como fluido com a densidade do solo (“solo hidrostático”);
 - Compressível: caso geral, com resistência ao cisalhamento;
- Conduto
 - Flexível;
 - Rígido;

Conduto flexível em “solo hidrostático”

- A falha se dá por flambagem;
- EI/D^3 é a rigidez do anel;

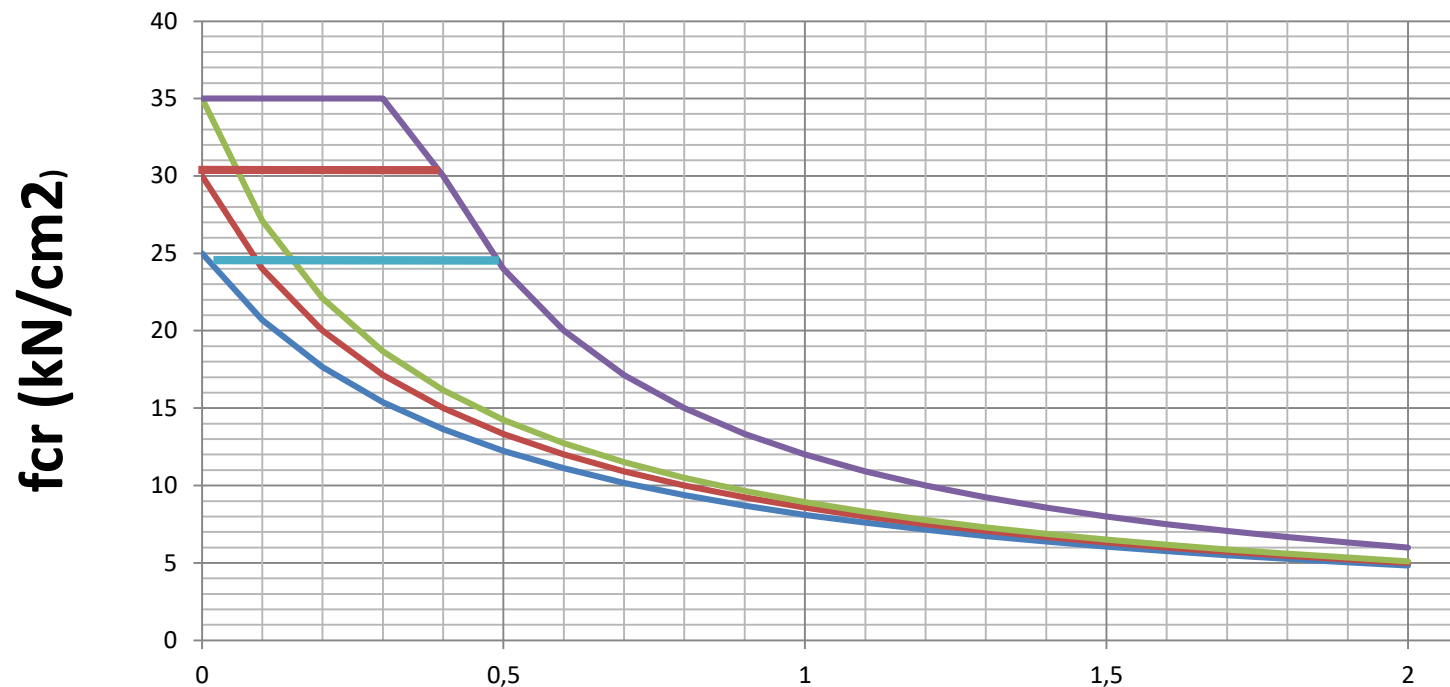
$$p_{cr} = \frac{24 \times EI}{D^3}$$

$$\sigma = \frac{p \times D}{2 \times A} \leftrightarrow f_{cr} = \frac{12 \times E \times I}{A \times D^2}$$



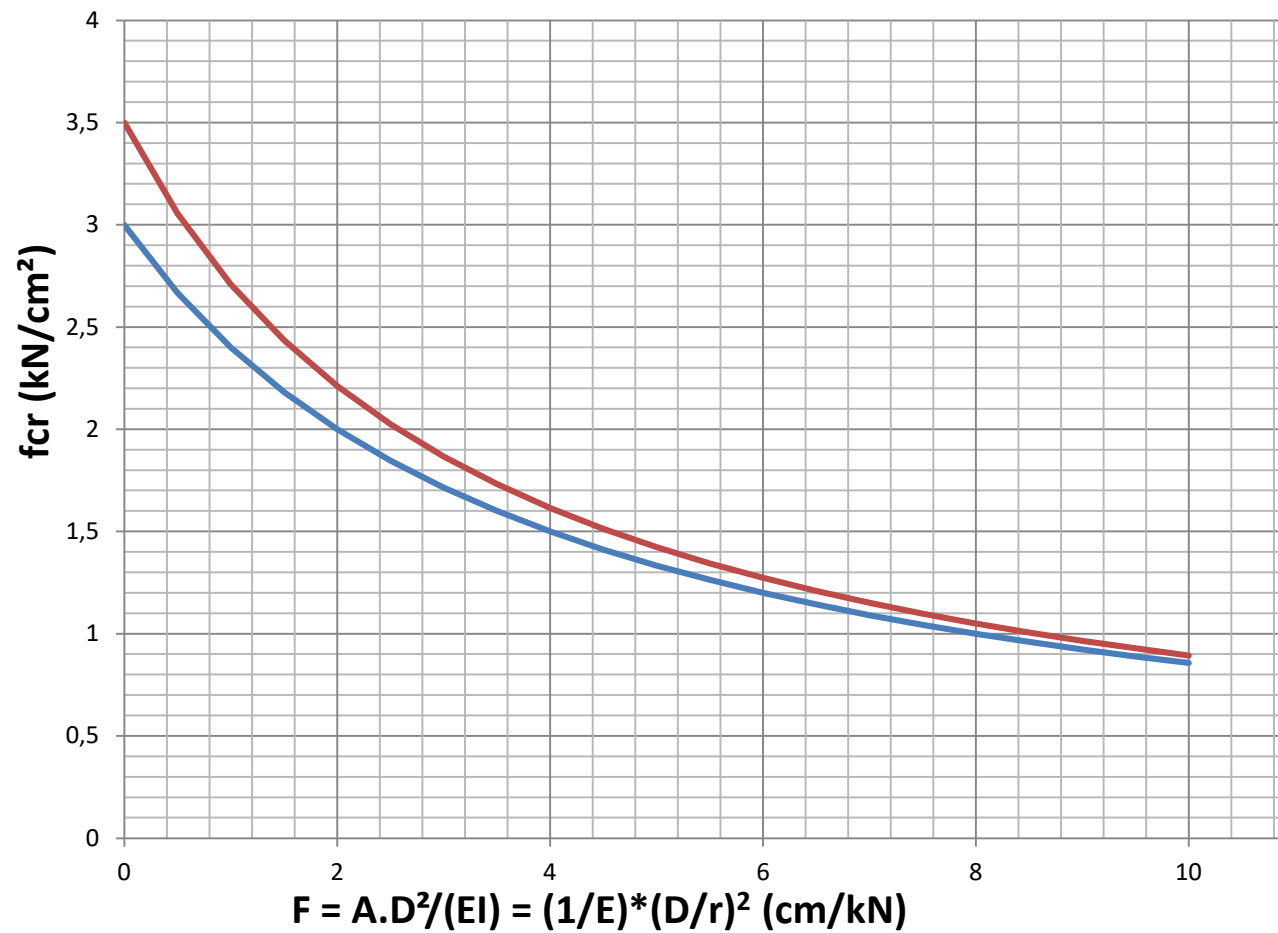
- Equação proposta por Southwell (1915): *on the collapse of tubes by external pressure;*

$$f_{cr} = \frac{f_y}{1 + \frac{f_y}{12} \left(\frac{A}{D}\right) \frac{D^3}{EI}}$$

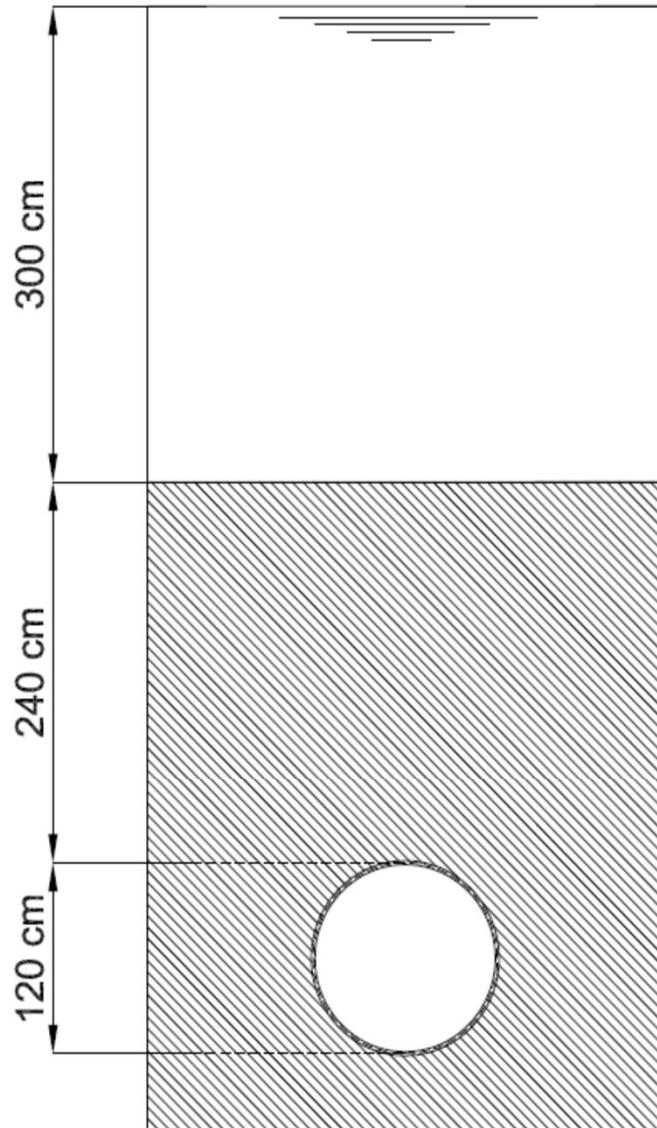


$$F = A \cdot D^2 / (EI) = (1/E) * (D/r)^2 \text{ (cm/kN)}$$

Aplicação da equação de Southwell ao concreto



Exemplo (adaptado de Watkins)



SEÇÃO TRANSVERSAL



$$A = 18,89 \text{ cm}^2 / \text{m}$$

$$I = 14,23 \text{ cm}^4 / \text{m}$$

Pressão no topo do bueiro:

$$P = 2,4 \times 19 + 3 \times 10 = 75,6 \text{ kN/m}^2$$

Tensão de compressão na seção do bueiro:

$$\sigma = 75,6 \times 1,2 / (2 \times 18,89) = 2,4 \text{ kN/cm}^2$$

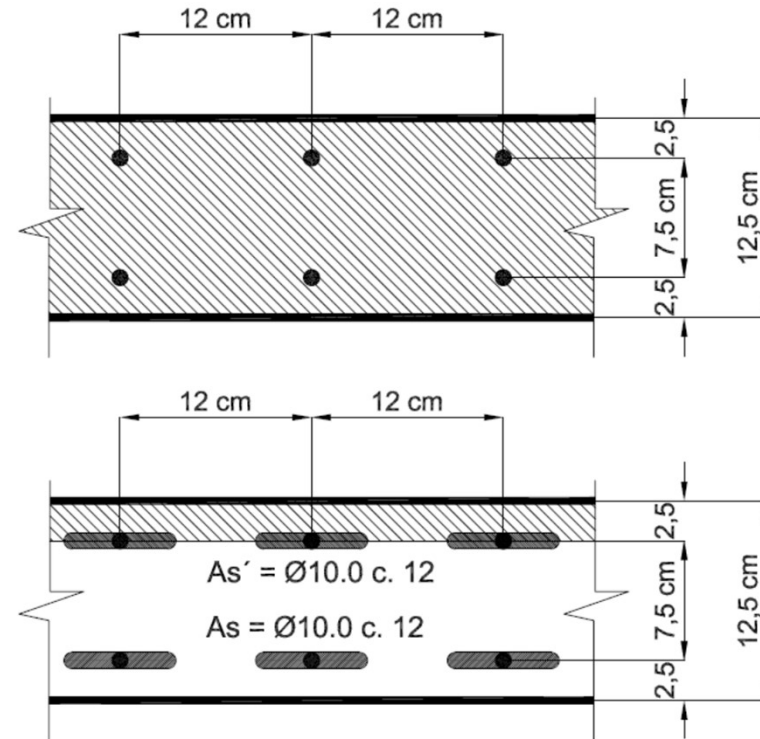
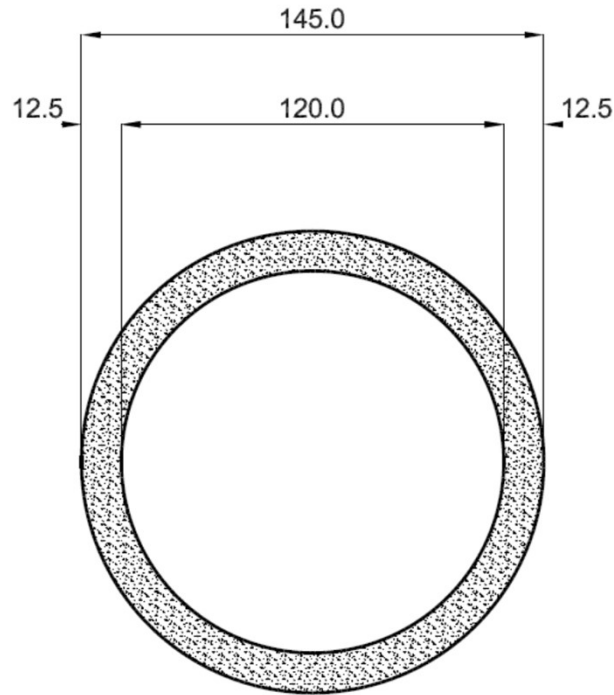
Cálculo de f_{cr} :

$$f_{cr} = 8,1 \text{ kN/cm}^2$$

Cálculo do fator de segurança:

$$FS = 8,1 / 2,4 = 3,375$$

Bueiro em concreto



- Tensão de compressão na seção do bueiro:
 - $\sigma = 75,6 \times 1,325 / (2 \times 326) = 0,17 \text{ kN/cm}^2$
- Cálculo de f_{cr} :
 - $f_{cr} = 3,31 \text{ kN/cm}^2$
- Cálculo do fator de segurança:
 - $CS = 3,31 / 0,17 = 19,5 \gg 3,0$

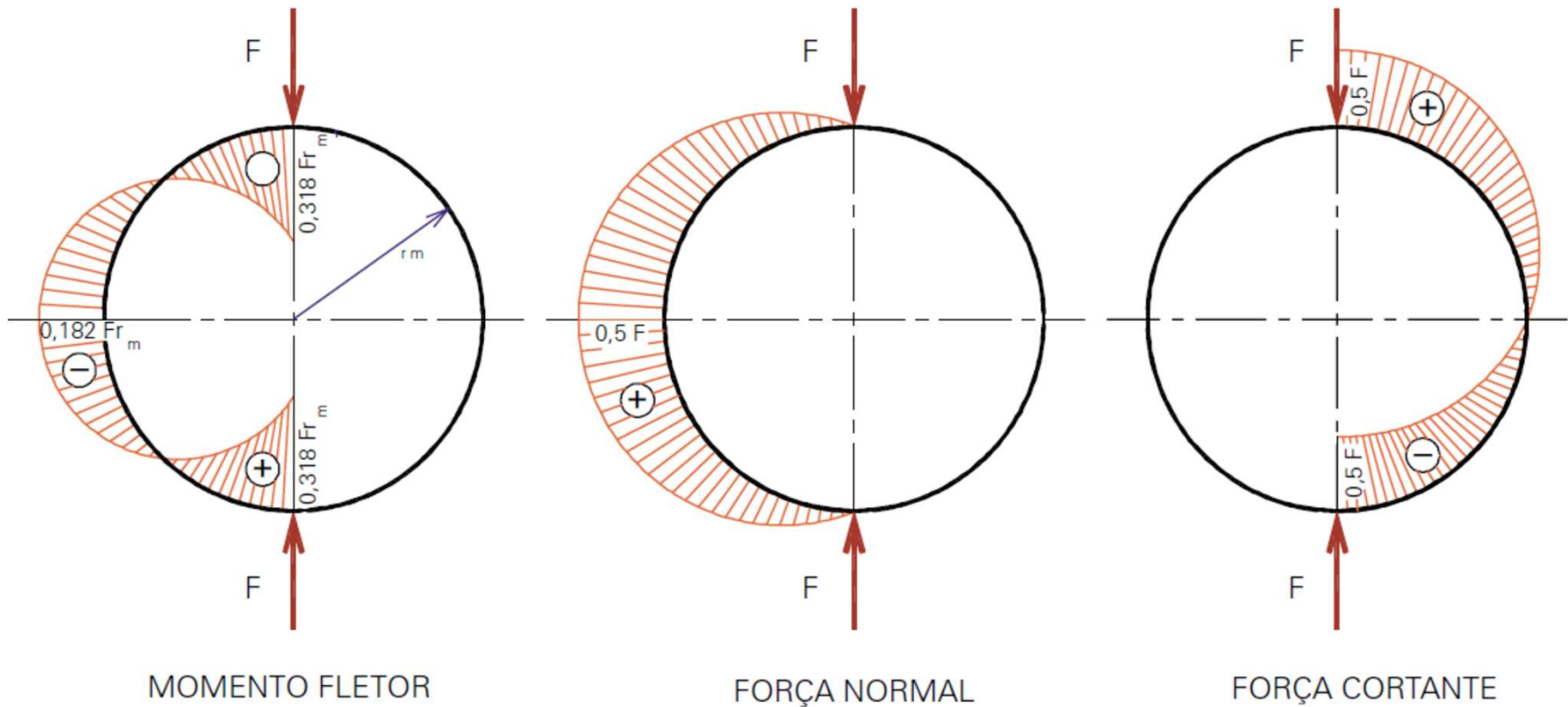
$$A_i = 2,5 \times 100 + 2 \times 5,7 \times 6,67 = 326 \text{ cm}^2$$

$$I = 2,5^3 + 5,7 \times 6,67 \times 7,5^2 = 2164 \text{ cm}^4$$

Ensaio dos três cutelos (*Three edge bearing test*)



Esforços no ensaio





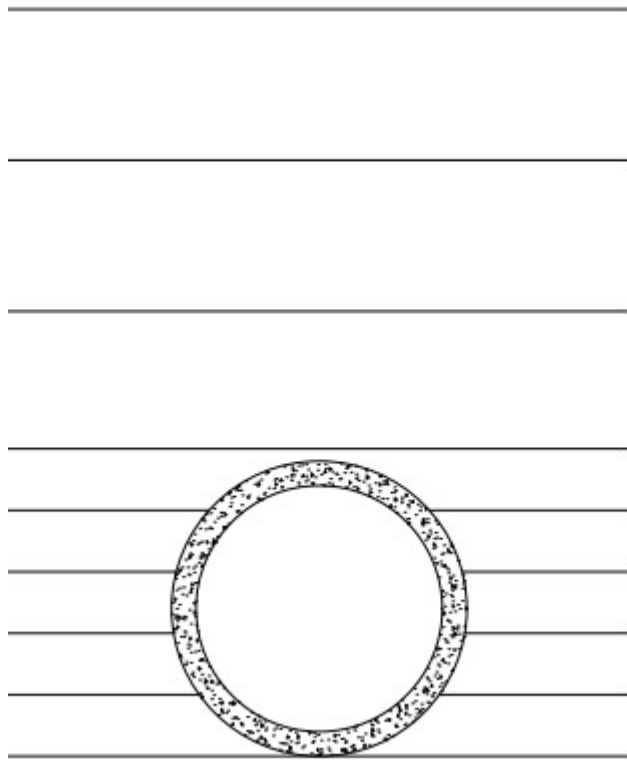
$$\Delta_y = 0,0186 \times \frac{W \times D^3}{EI}$$

$$\Delta_x = 0,0170 \times \frac{W \times D^3}{EI}$$

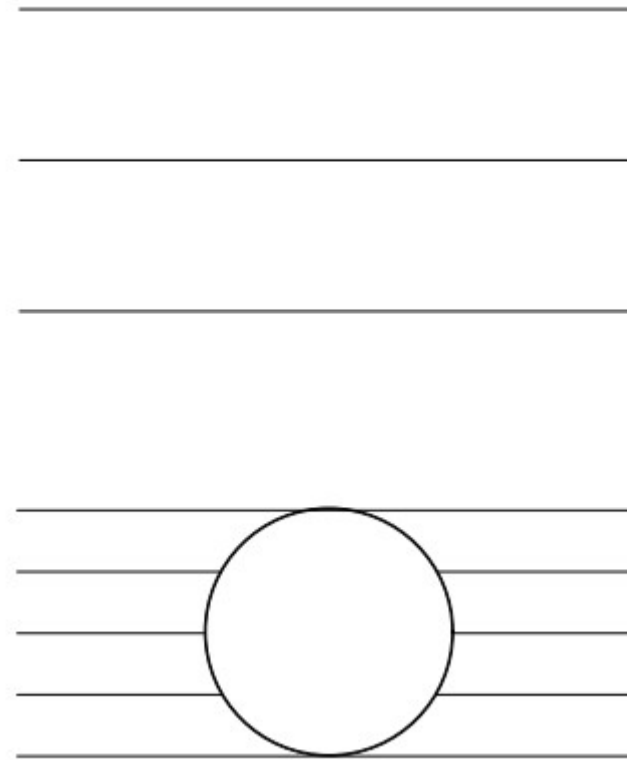
$$F = \frac{1}{E} \left(\frac{D}{r} \right)^2 = 53,8 \times \frac{A}{D} \times \frac{\Delta_y}{W}$$

$$F = \frac{1}{E} \left(\frac{D}{r} \right)^2 = 58,8 \times \frac{A}{D} \times \frac{\Delta_x}{W}$$

Solo “compressível”

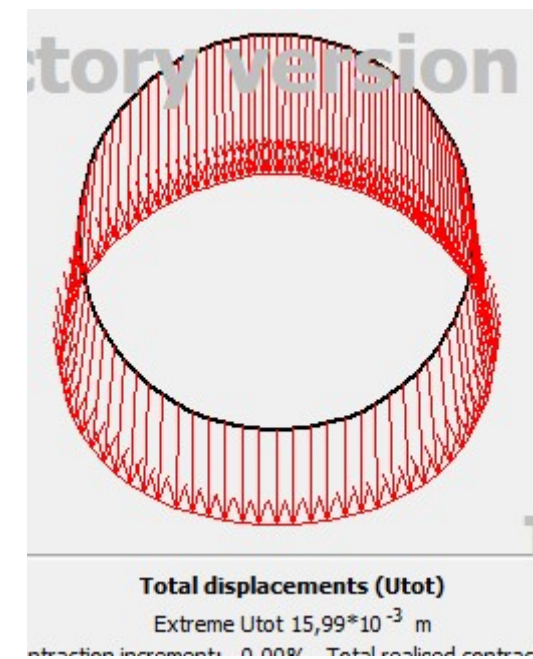
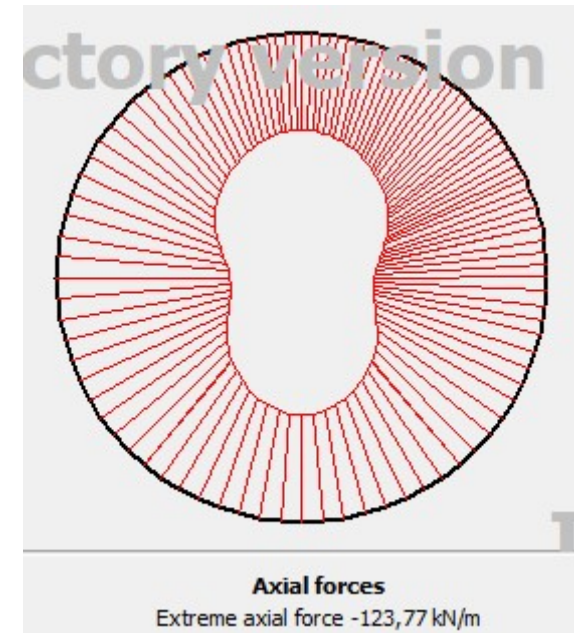
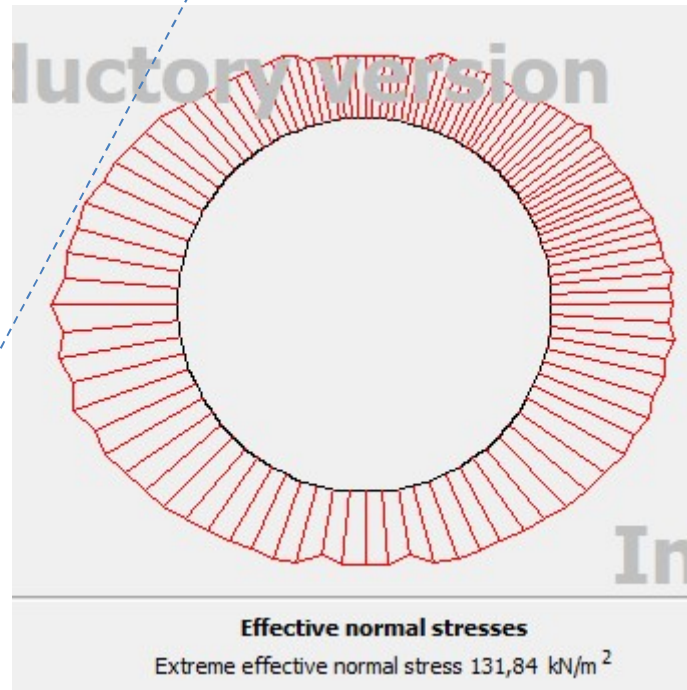
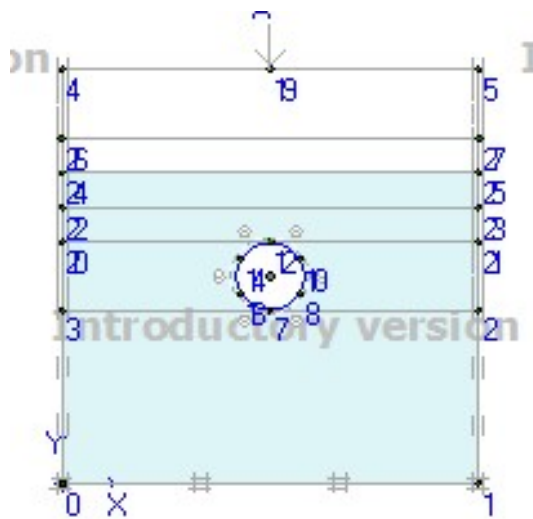
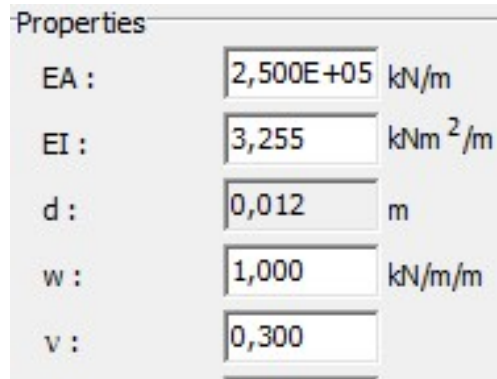
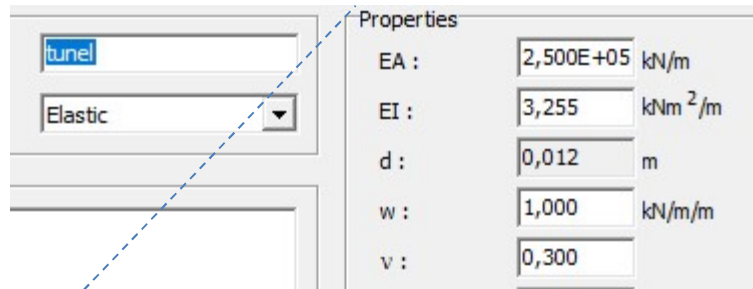


CONDUTO RÍGIDO

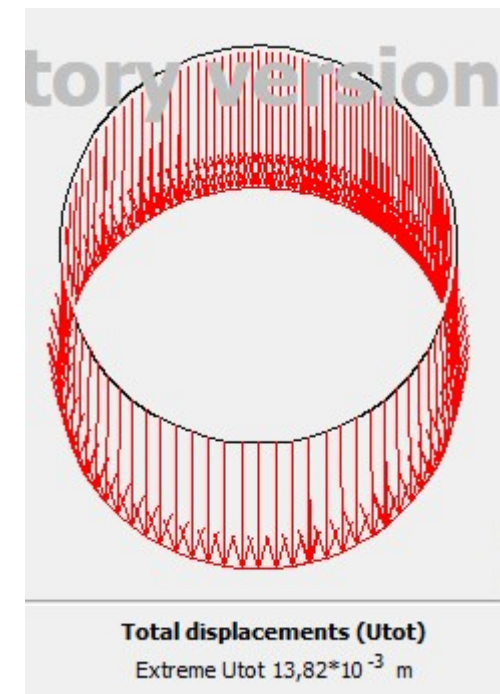
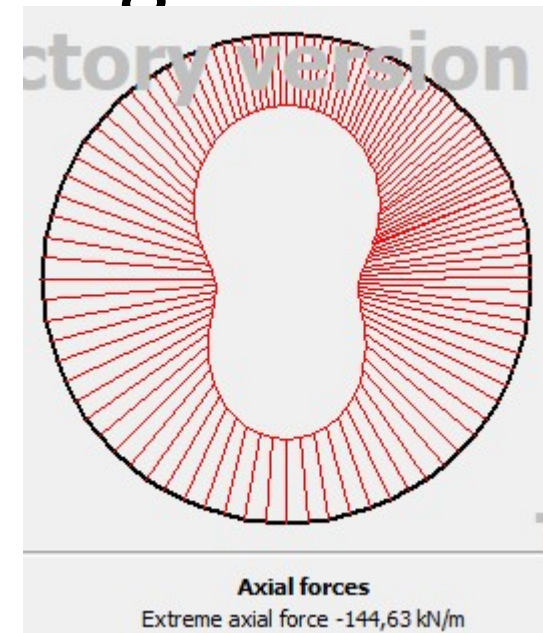
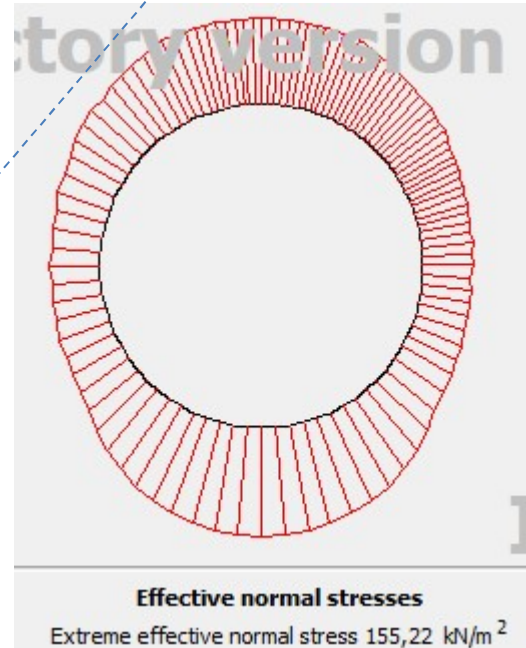
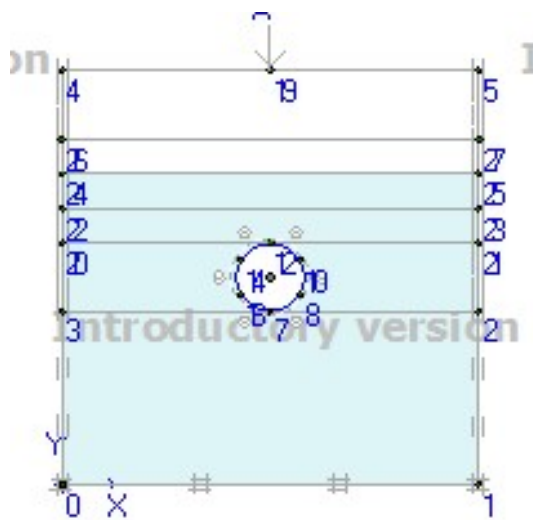
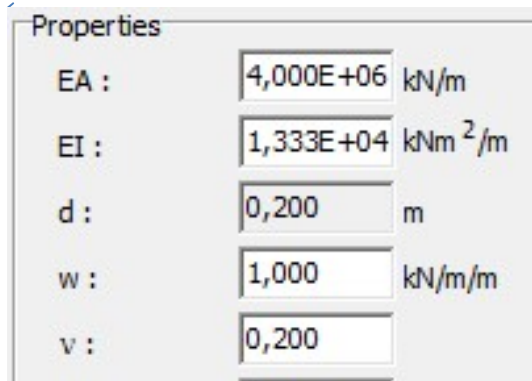
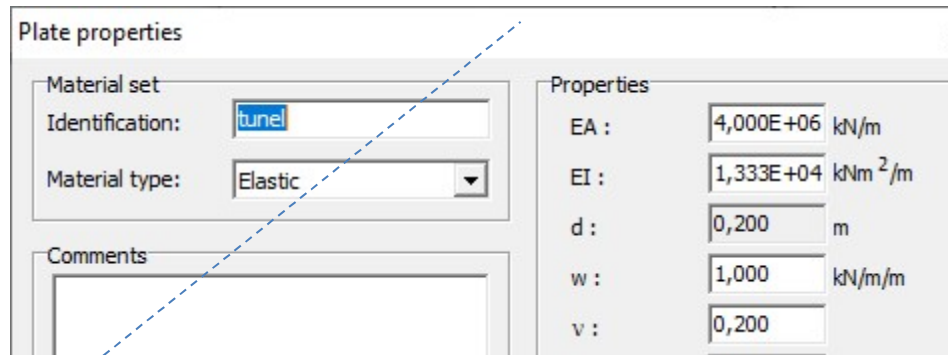


CONDUTO FLEXÍVEL

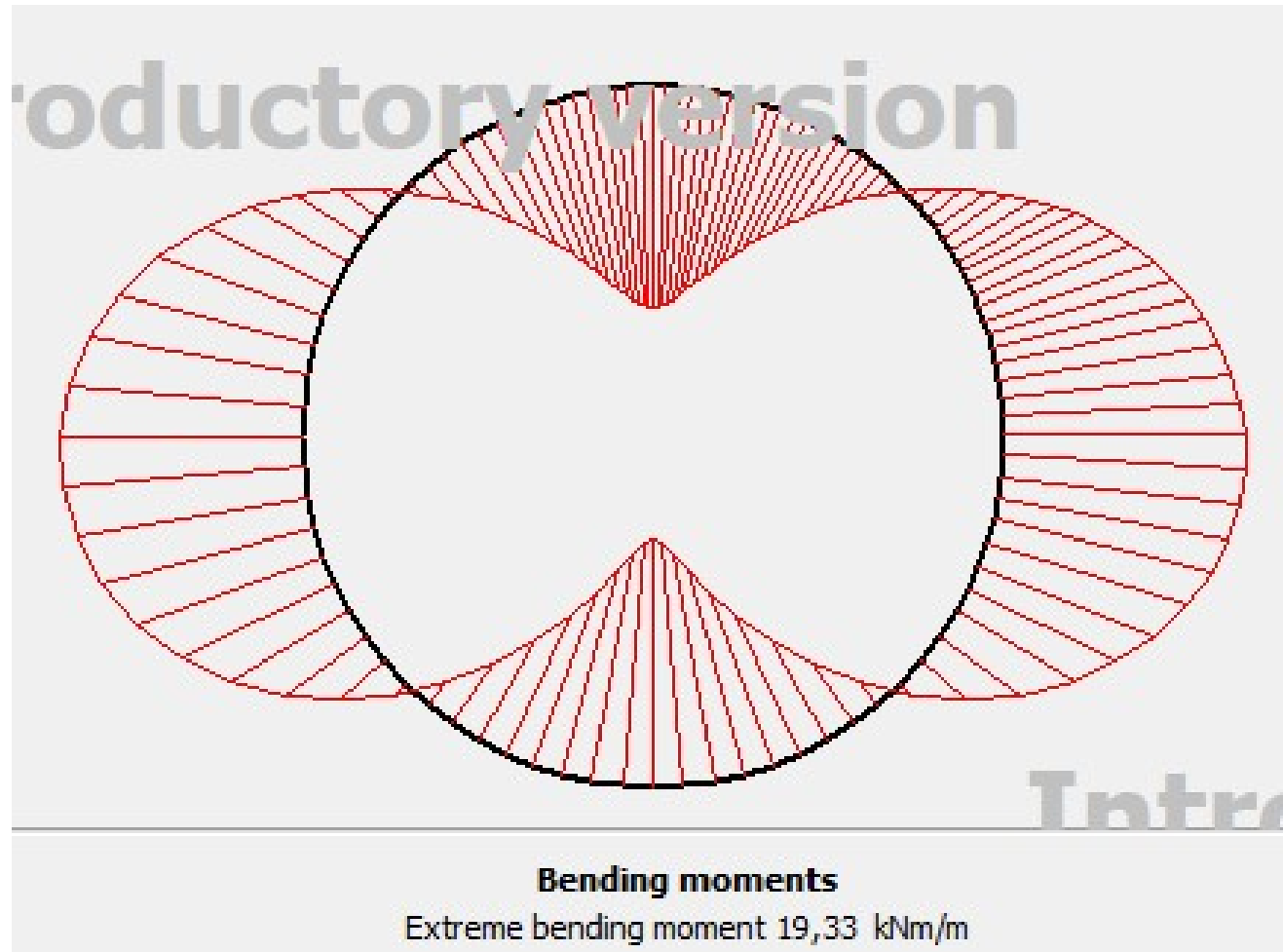
Análise de um conduto flexível



Análise de um conduto rígido

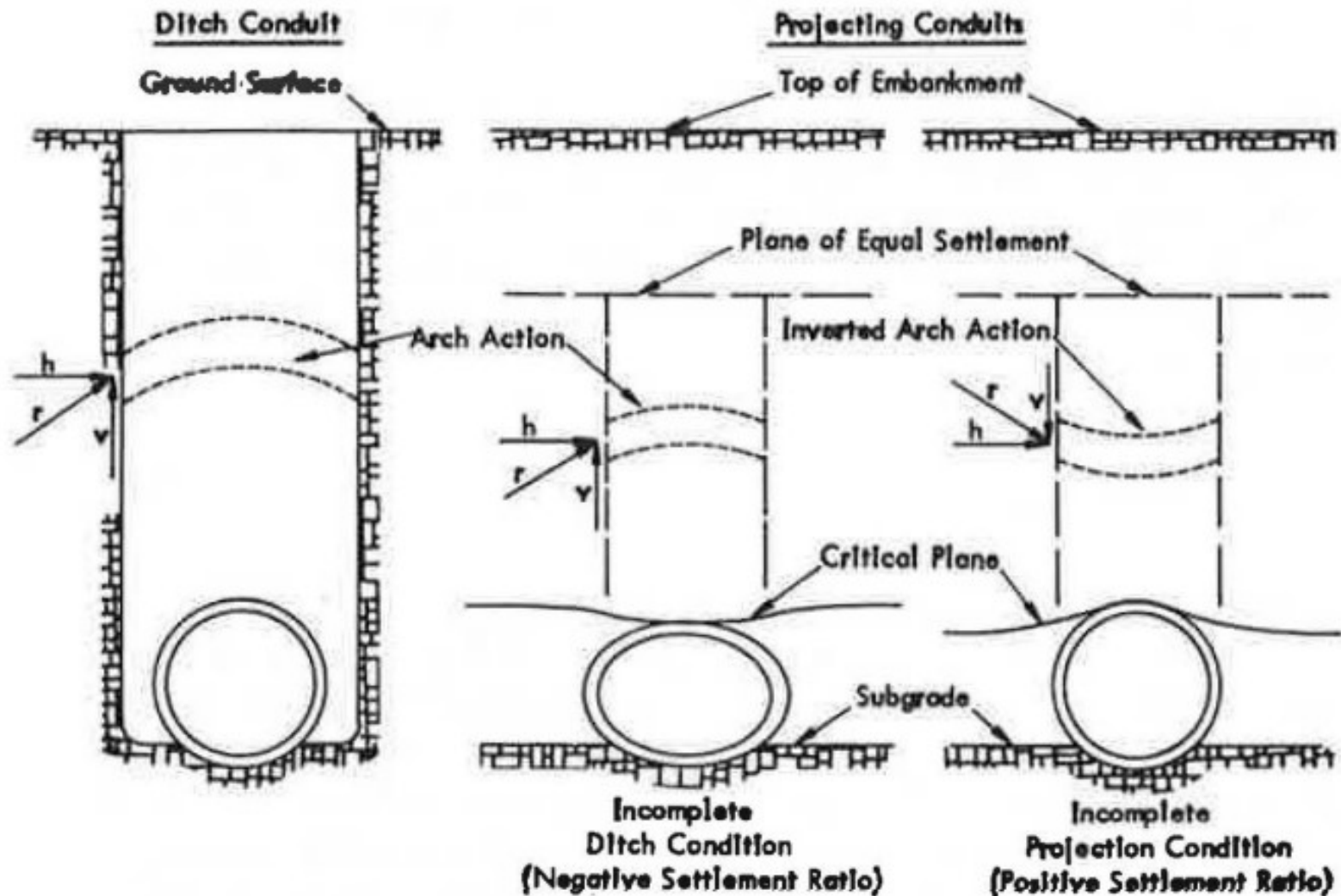


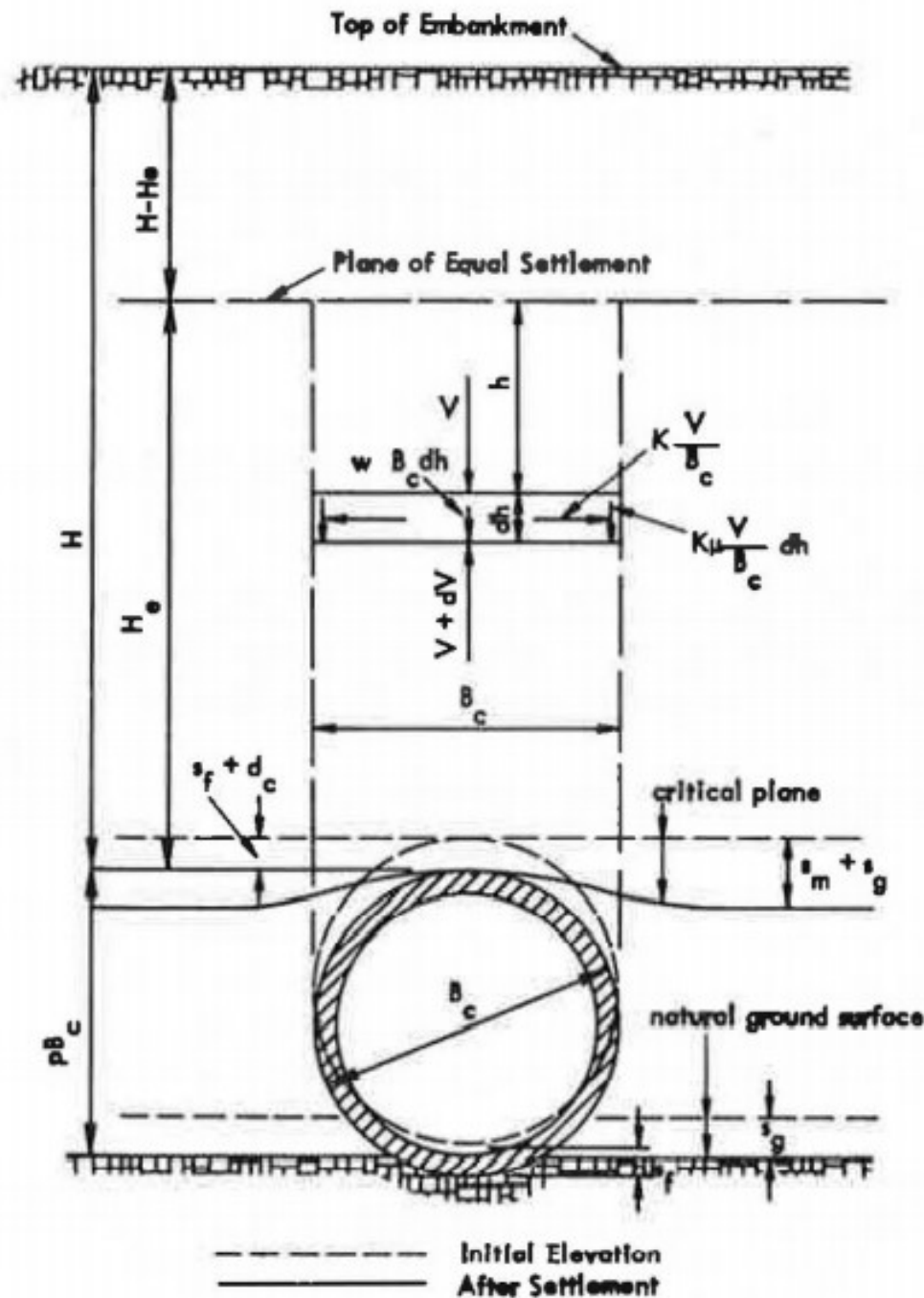
Momentos na estrutura rígida



Carregamentos para projeto (Marston-Spangler)

Figure 1. Arch action over underground conduits.





$$V + dV = V + wB_c dh \pm 2K\mu \frac{V}{B_c} dh$$

$$W_c = C_c w B_c^2$$

$$C_c = \frac{e^{\pm 2K\mu \frac{H}{B_c}} - 1}{\pm 2K\mu}$$

Figure 5. Relation of μ , K , and $K\mu$.

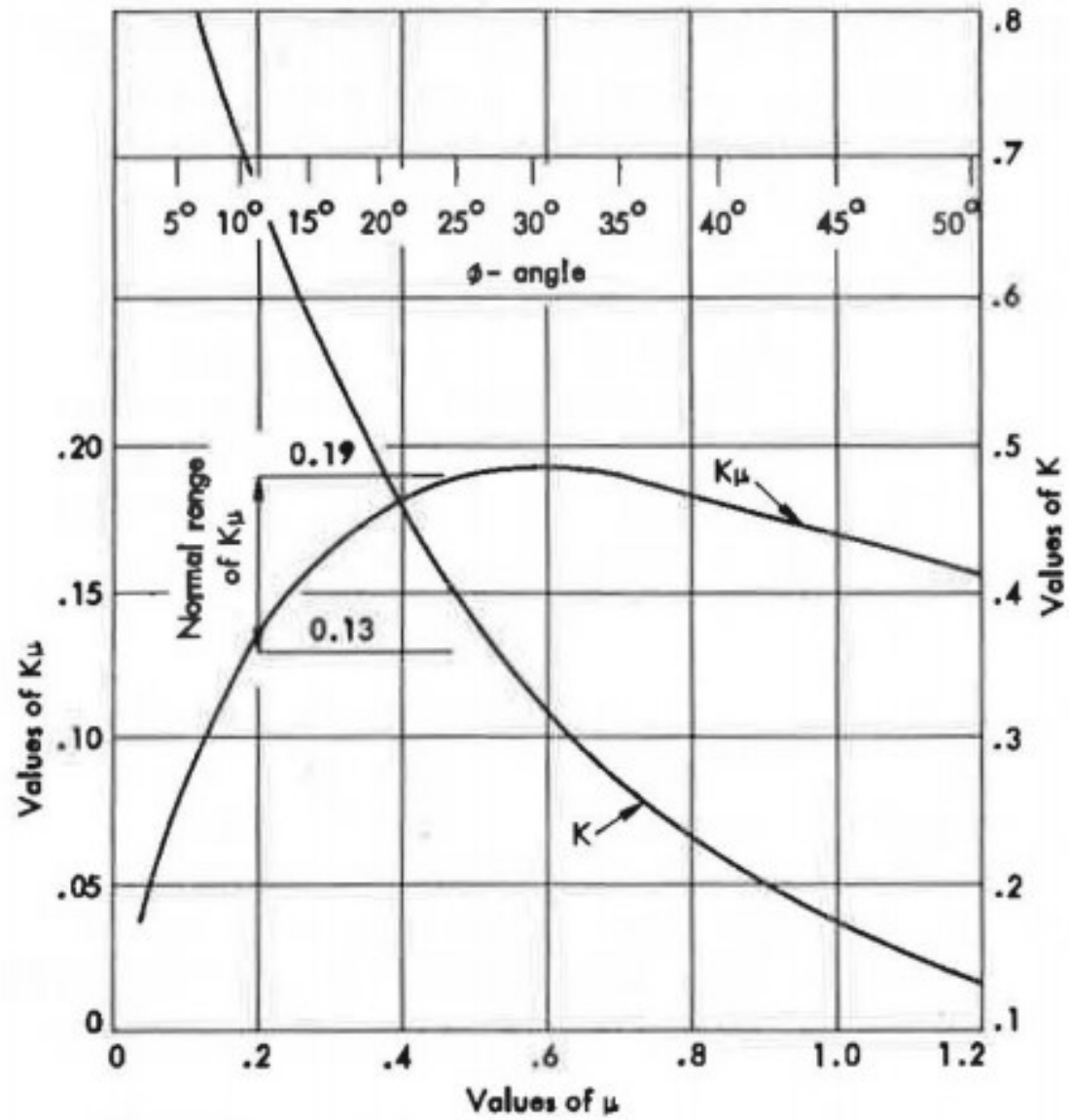


Figure 4. Calculation diagram.

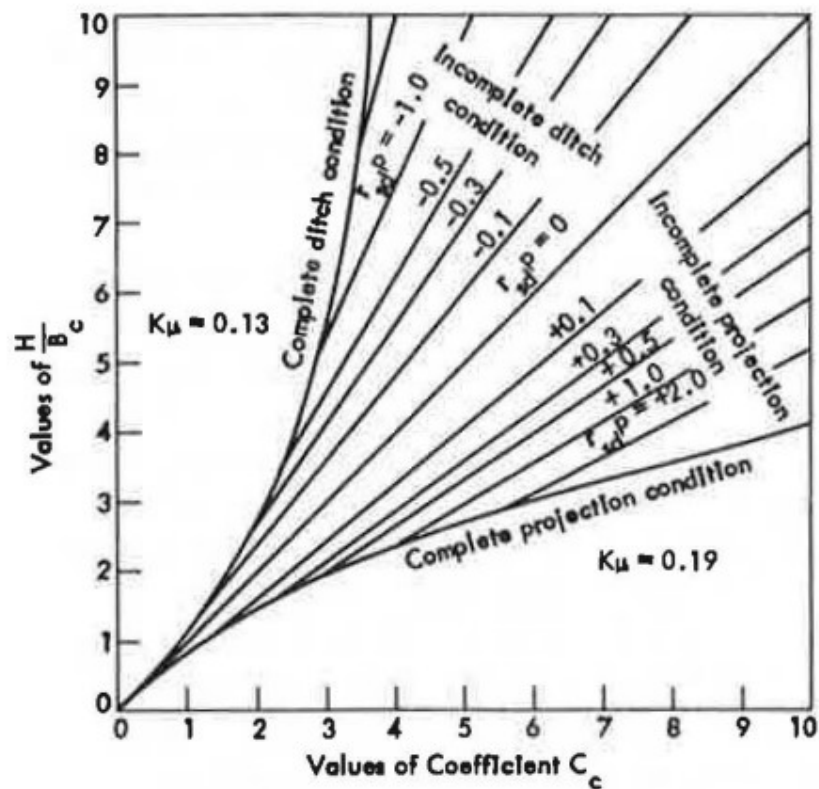


Table 1. Values of constants A and X for extrapolating values of C_c versus H/B_c .

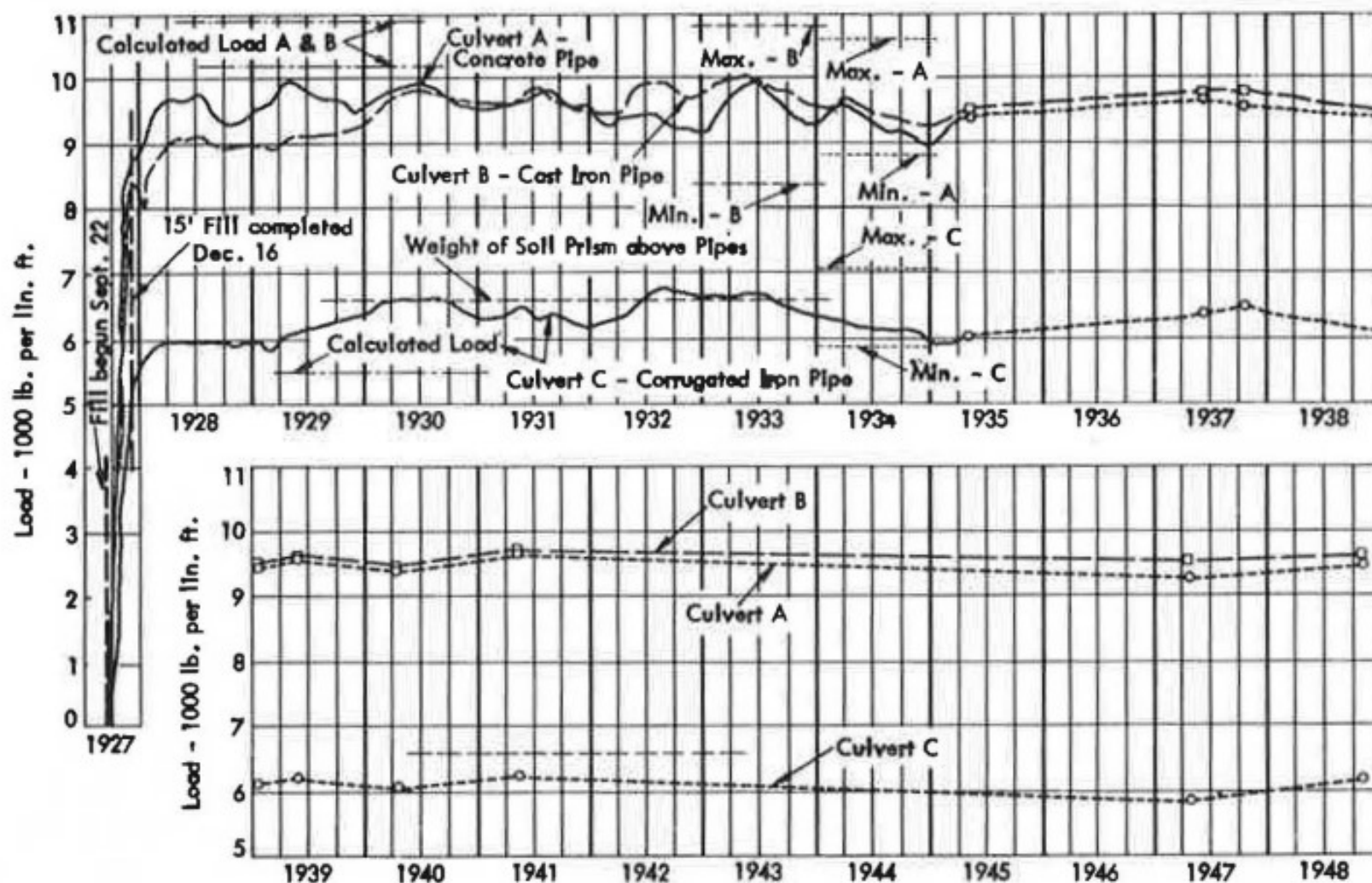
Incomplete Ditch Condition ($K\mu = 0.13$)			Incomplete Projection Condition ($K\mu = 0.19$)		
r_{sp}	A	X	r_{sp}	A	X
0	1.00	0	+0.1	1.23	-0.02
-0.1	0.82	+0.05	+0.3	1.39	-0.05
-0.3	0.69	+0.11	+0.5	1.50	-0.07
-0.5	0.61	+0.20	+0.7	1.59	-0.09
-0.7	0.55	+0.25	+1.0	1.69	-0.12
-1.0	0.47	+0.40	+2.0	1.93	-0.17
-2.0	0.30	+0.91	+3.0	2.08	-0.20

LONG-TIME MEASUREMENT OF LOADS ON THREE PIPE CULVERTS
Merlin G. Spangler, Engineering Research Institute, Iowa State University

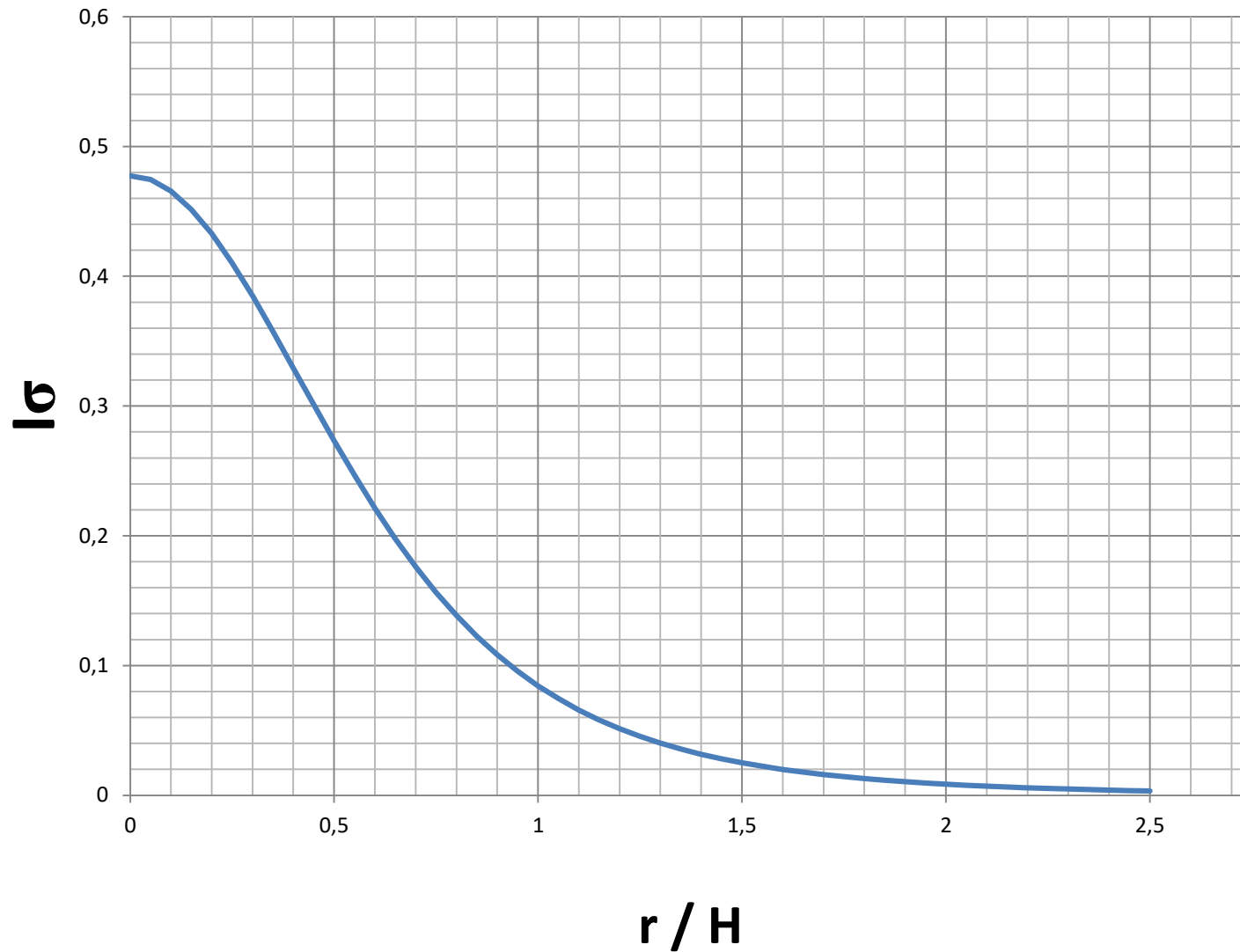
Figure 6. Experimental culverts before fill construction.



Figure 10. Time-load curves.



$$\sigma_z = \frac{Q}{z^2} I_\sigma \quad I_\sigma = \frac{3}{2\pi} \left[\frac{1}{1 + (r/z)^2} \right]^{\frac{5}{2}}$$



Fatores de berço

TABLE 23.3 LOAD FACTORS (L_f) FOR RIGID PIPES (ACPA, 1970, p. 336-339) BASED ON SPECIFIED CLASSES OF BEDDING

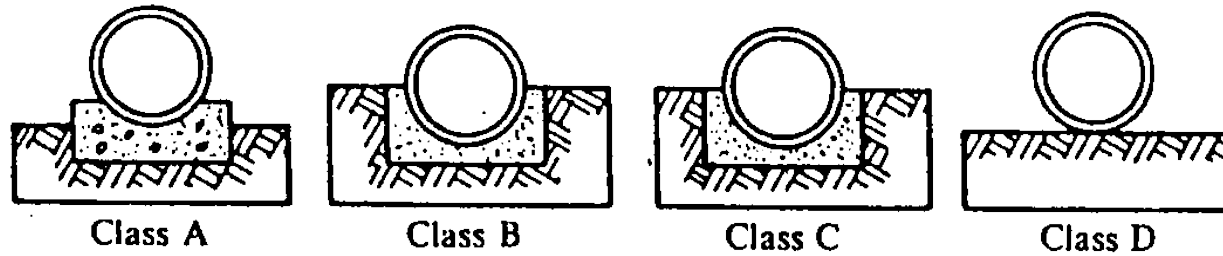


Fig. 23.12 Class A—concrete cradle; B—compacted granular material; C—compacted granular material of densely compacted backfill; D—flat subgrade.

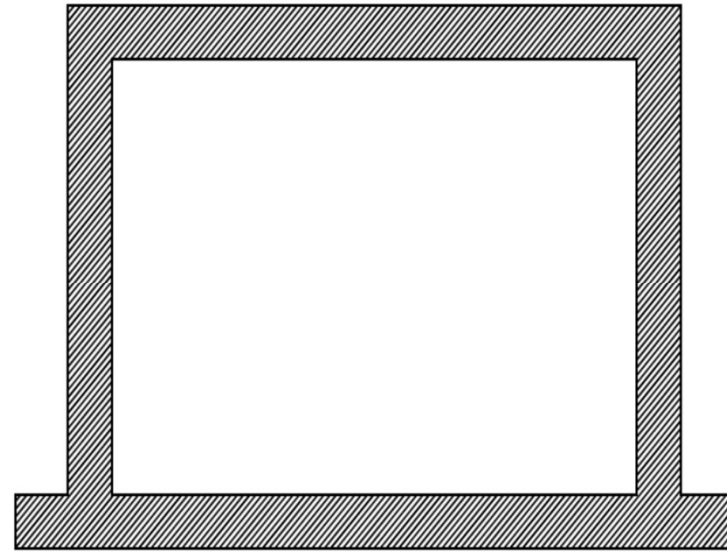
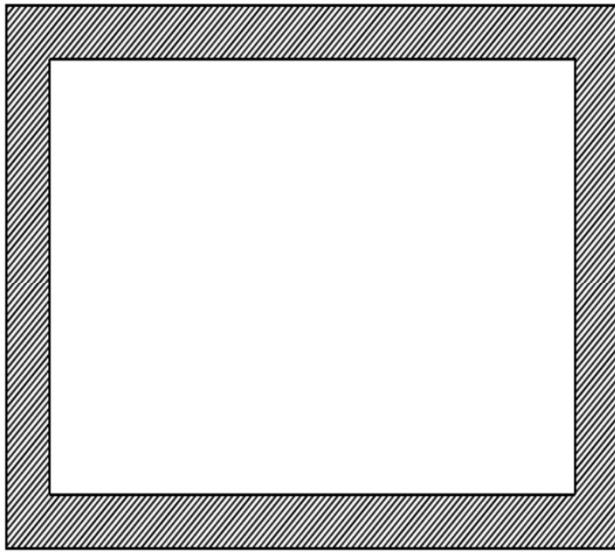
	<i>Class A</i>	<i>Class B</i>	<i>Class C</i>	<i>Class D</i>
Embankment	4.8	2.6	2.0	1.2
Trench ^a	4.8	1.9	1.5	1.1
	3.4			
	2.8			

^a4.8 for 1.0% reinforcing steel; 3.4 for 0.4% reinforcing steel; 2.8 for plain.

Galerias

- Consideração das fases de construção;
- Carregamentos;
- Subpressão;
- Estanqueidade;
- Sistemas estruturais;

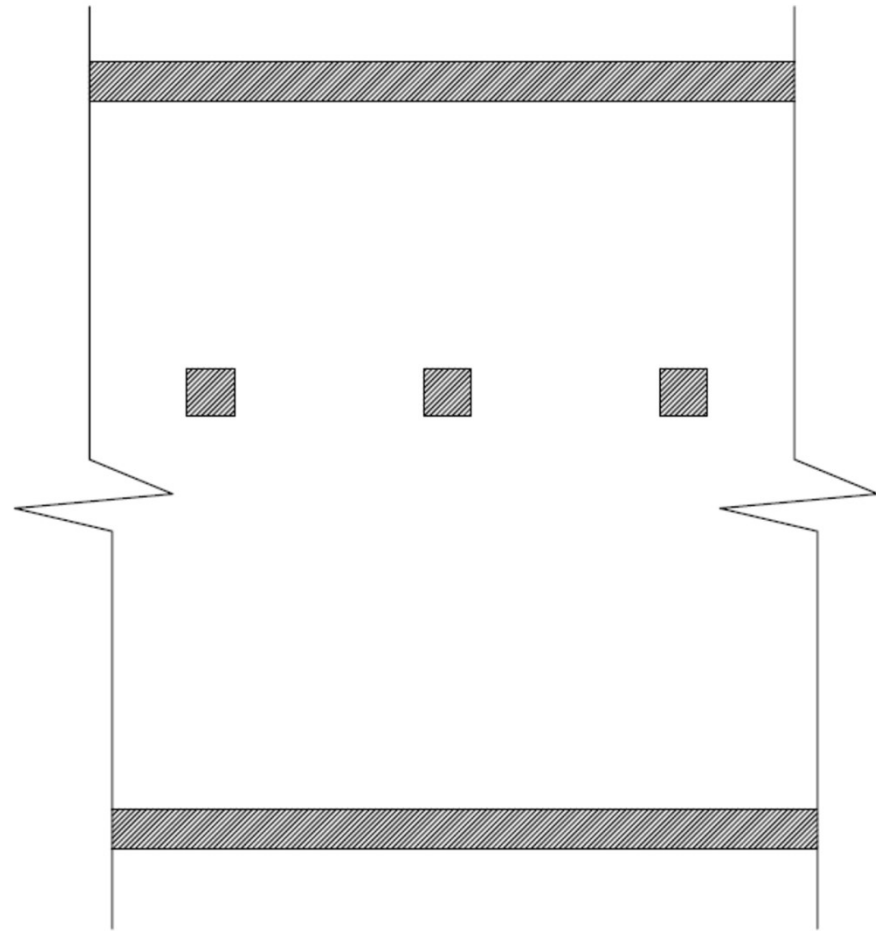
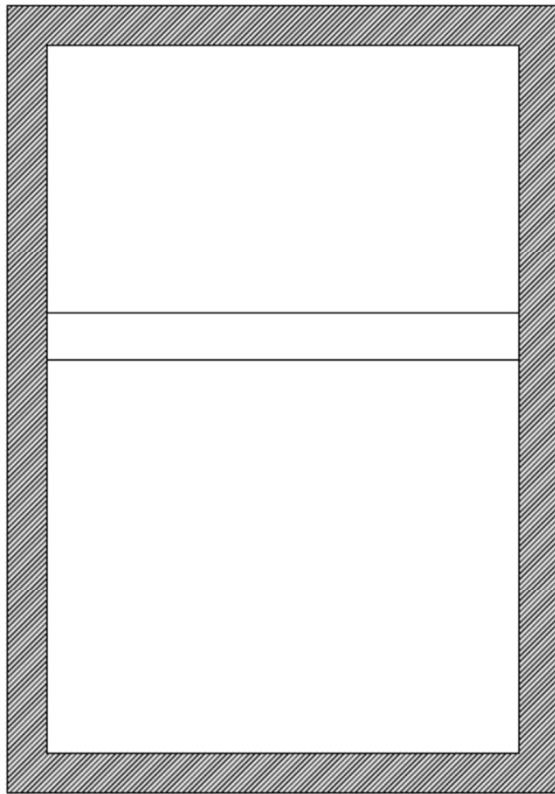
Sistemas estruturais

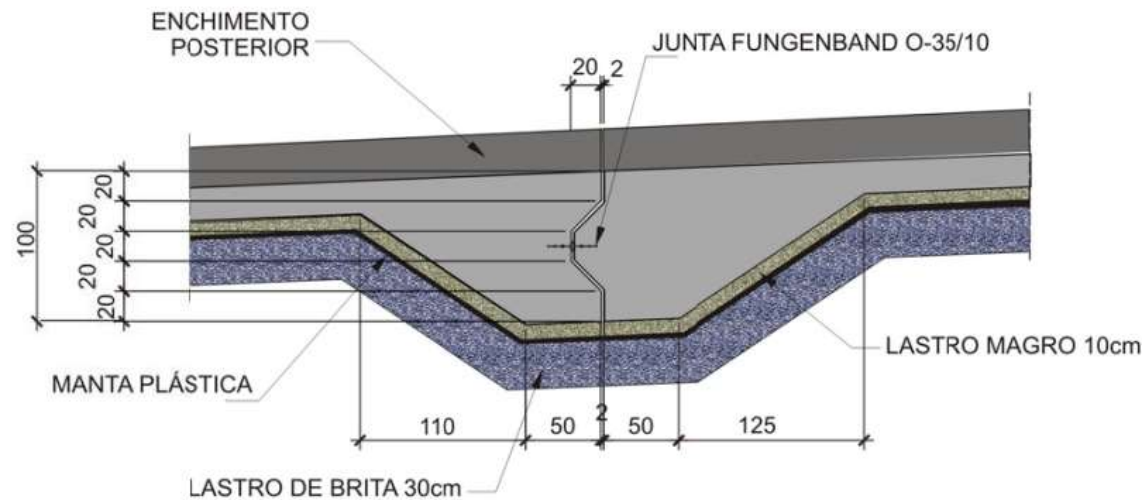
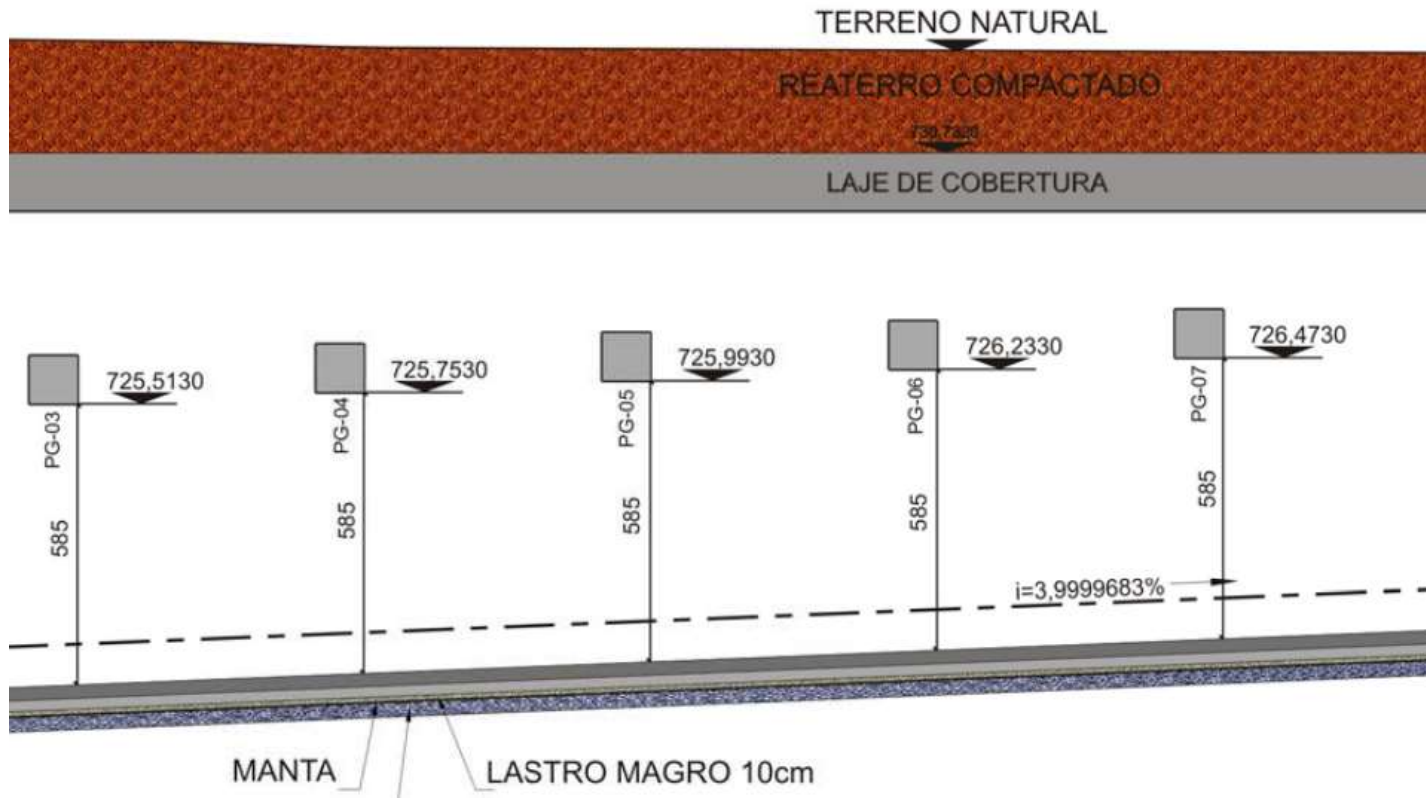


Vãos pequenos: digamos 3 m a 10 m



Grandes alturas: pergolado







Grandes vãos

