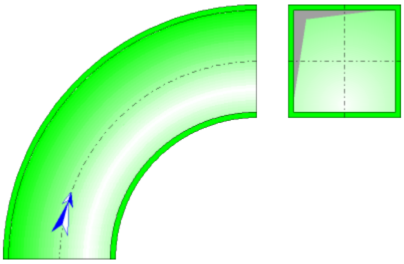
Smooth Bend
Rectangular Cross-Section
(MILLER)



Model description:

This model of component calculates the head loss (pressure drop) of a bend smoothly curved whose cross-section is rectangular and constant. In addition, the flow is assumed fully developed and stabilized upstream of the bend.

An option allows to take into account the effect of the straight length at the exit of the bend.

Model formulation:

Hydraulic diameter (m):

$$D = \frac{2 \cdot b \cdot W}{b + W}$$

([1] equation 9.5)

Cross-section area (m^2):

$$A = b \cdot W$$

Mean velocity (m/s):

$$U = \frac{Q}{A}$$

Length measured along the axis (m):

$$L = 2 \cdot \pi \cdot r \cdot \frac{\theta_b}{360}$$

Mass flow rate (kg/s):

$$G = Q \cdot \rho$$

Fluid volume (m^3):

$V = A \cdot L$

Fluid mass (kg):

$M = V \cdot \rho$

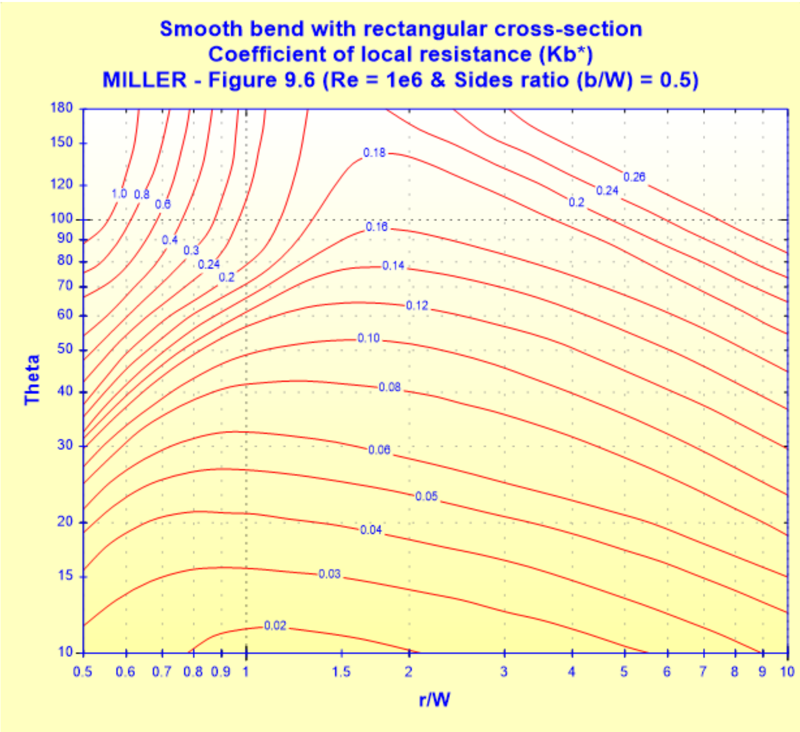
Reynolds number:

$$\text{Re} = \frac{U \cdot D}{\nu}$$ ([1] equation 9.6)

Basic resistance coefficient:

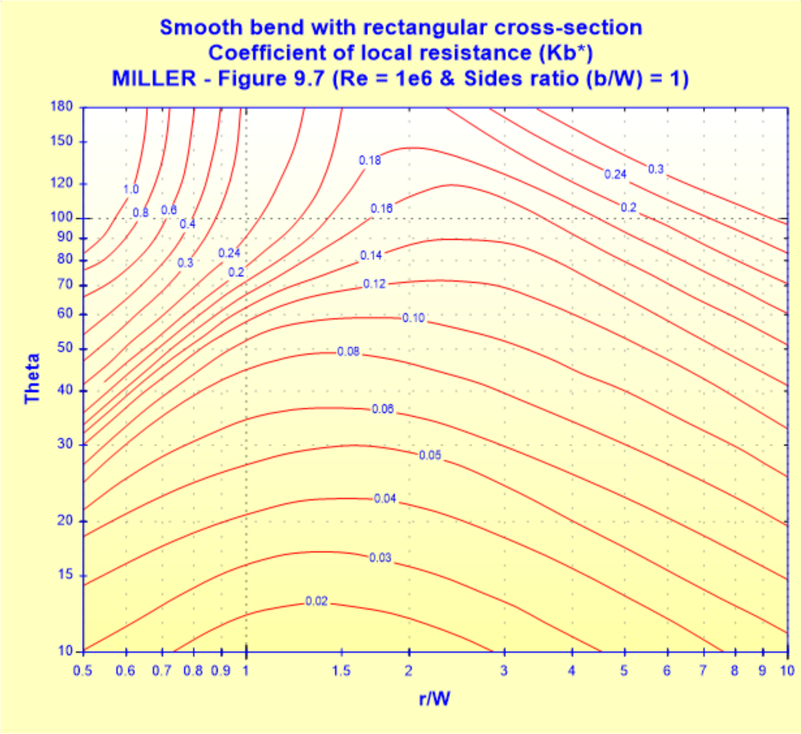
$$K_b^* = f\left(\frac{r}{W}, \theta_b\right)$$ ([1] figures 9.6 – 9.7 – 9.8)

- Sides ratio b/W = 0.5



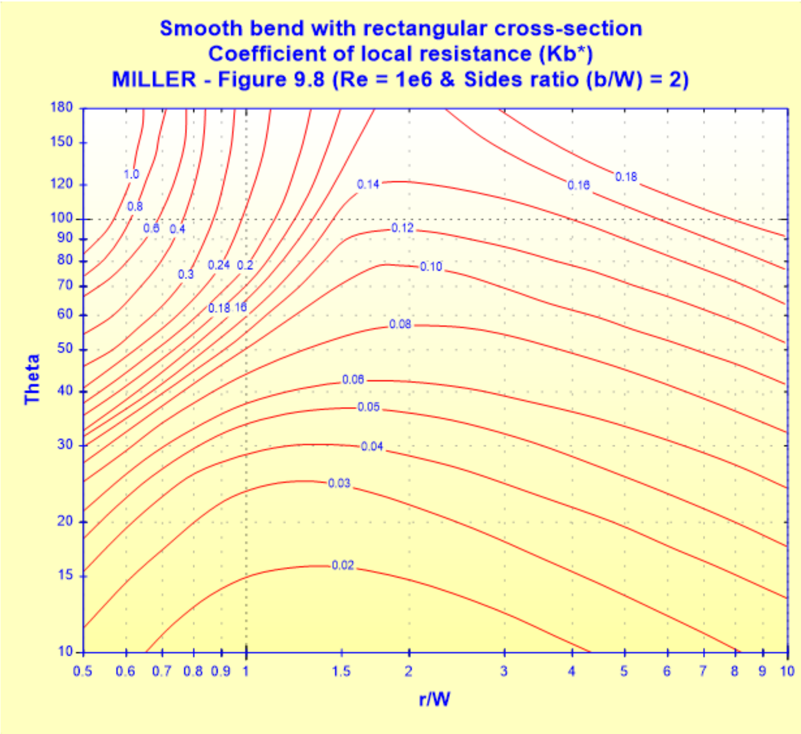
([1] figure 9.6)

- Sides ratio b/W = 1



([1] figure 9.7)

■ Sides ratio b/W = 2



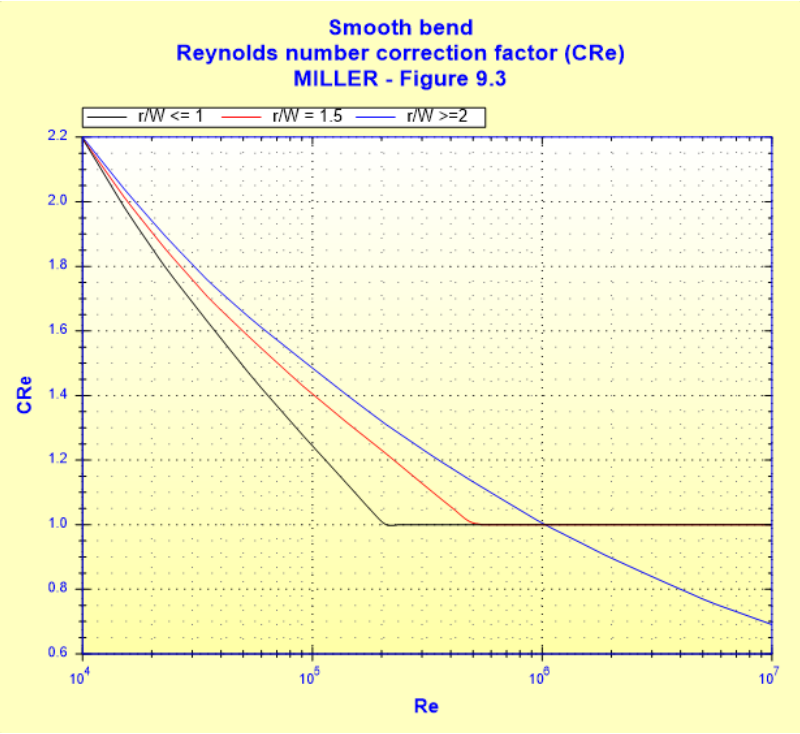
([1] figure 9.8)

For any sides ratio 'b/W' between 0.5 and 2, the coefficient K_b^* is obtained by curvilinear interpolation between the values of K_b^* calculated for aspect ratios of 0.5, 1 and 2.

Reynolds number correction factor:

$$C_{Re} = f\left(\text{Re}, \frac{r}{W}\right)$$

([1] figure 9.3)



- r/W $\geq$ 1

$$C_{Re} = f\left(\text{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3)

- r/W $<$ 1
  - r/W $>$ 0.7 or $K_b^* < 0.4$

$$C_{Re} = f\left(\text{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3 with r/W=1)

  - otherwise (r/W $\leq$ 0.7 and $K_b^* \geq 0.4$)

$$C_{Re} = \frac{K_b^*}{K_b^* - 0.2C'_{Re} + 0.2}$$ ([1] equation 9.2)

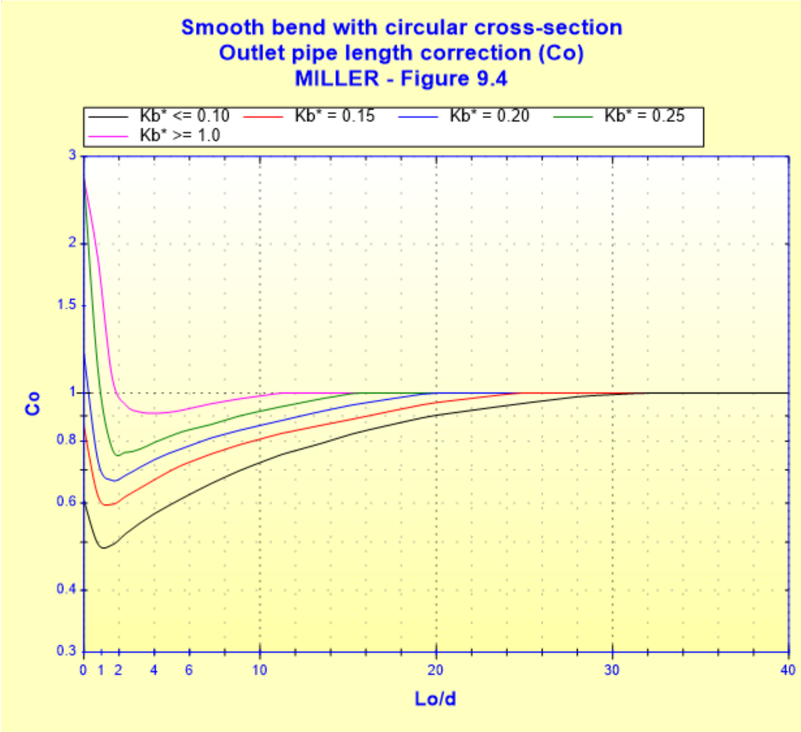
with:

$$C'_{Re} = f\left(\text{Re}, \frac{r}{D}\right)$$ ([1] figure 9.3 with r/W=1)

Outlet pipe length correction factor (optional):

- correction factor for circular cross-section
  - $\theta_b < 100°$

$$C_o = f\left(\frac{L_o}{D}, K_b^*\right)$$ ([1] figure 9.4)



- $\theta_b \geq 100°$

  $$C_o = 1$$ (negligible effect)

■ correction factor for rectangular cross-section

- b/W < 0.7 and Lo/D > 1

  $$C_{or} = 1 - \frac{1 - C_o}{2}$$

- b/W > 1 and Lo/D < 1
  - ♦ 1.5 < r/W < 3

    $$C_{or} = 2$$

  - ♦ r/W ≤ 1.5 or r/W ≥ 3

    $$C_{or} = C_o$$

- otherwise

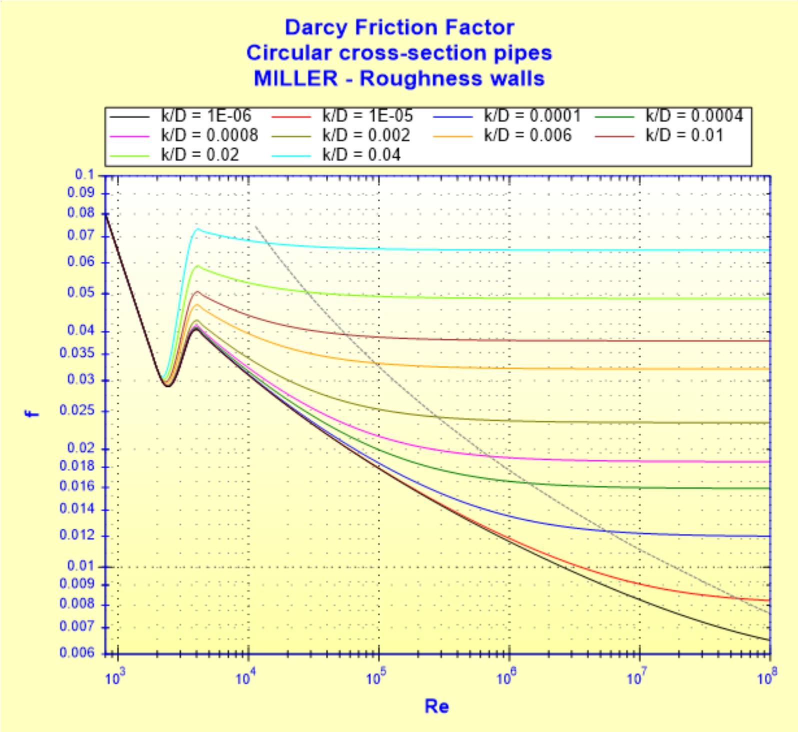
  $$C_{or} = C_o$$

If this option is not activated, the factors C_o and C_{or} are equal to unity.

Darcy friction factor:

$$f = f\left(\mathrm{Re}, \frac{k}{D}\right)$$

See Straight Pipe - Rectangular Cross-Section and Roughness Walls (MILLER)



Roughness correction factor:

$$C_f = \frac{f_{rough}}{f_{smooth}}$$

([1] equation 9.3)

with:

f_{rough}: Darcy friction factor for rough pipe at Re

f_{smooth}: Darcy friction factor for smooth pipe (k = 0) at Re

For Re > 10^6, C_f is calculated from equation (9.3) for Re = 10^6

Corrected loss coefficient:

$$K_b = K_b^* \cdot C_{Re} \cdot C_{or} \cdot C_f$$

([1] equation 9.4)

Total pressure loss coefficient (based on the mean velocity in the bend)

$$K = K_b$$

Total pressure loss (Pa):

$$\Delta P = K \cdot \frac{\rho \cdot U^2}{2}$$

([1] equation 8.1b)

Total head loss of fluid (m):

$$\Delta H = K \cdot \frac{U^2}{2 \cdot g}$$

([1] equation 8.1a)

Hydraulic power loss (W):

$$Wh = \Delta P \cdot Q$$

Straight length of equivalent pressure loss (m):

$$L_{eq} = K \cdot \frac{D}{f_{rough}}$$

Symbols, Definitions, SI Units:

W	Cross-section height (m)
b	Cross-section width (m)
D	Bend hydraulic diameter (m)
d	Bend internal diameter (m)
A	Cross-section area (m^2)
Q	Volume flow rate (m^3/s)
U	Mean velocity (m/s)
L	Length measured along the axis (m)
r	Radius of curvature (m)
θ_b	Curvature angle (°)
G	Mass flow rate (kg/s)
V	Fluid volume (m^3)
M	Fluid mass (kg)
Re	Reynolds number ()
K_b^*	Basic loss coefficient ()
C_{Re}	Reynolds number correction factor ()
C_o	Outlet pipe length correction factor for circular cross-section ()
C_{or}	Outlet pipe length correction factor for rectangular cross-section ()
L_0	Length of the straight section downstream of the bend (m)
f	Darcy friction factor ()
k	Absolute roughness of walls (m)
C_f	Roughness correction factor ()
K_b	Corrected loss coefficient ()
K	Total pressure loss coefficient (based on the mean velocity in the bend) ()
ΔP	Total pressure loss (Pa)
ΔH	Total head loss of fluid (m)
Wh	Hydraulic power loss (W)
L_{eq}	Straight length of equivalent pressure loss (m)
ρ	Fluid density (kg/m^3)
ν	Fluid kinematic viscosity (m^2/s)
g	Gravitational acceleration (m/s^2)

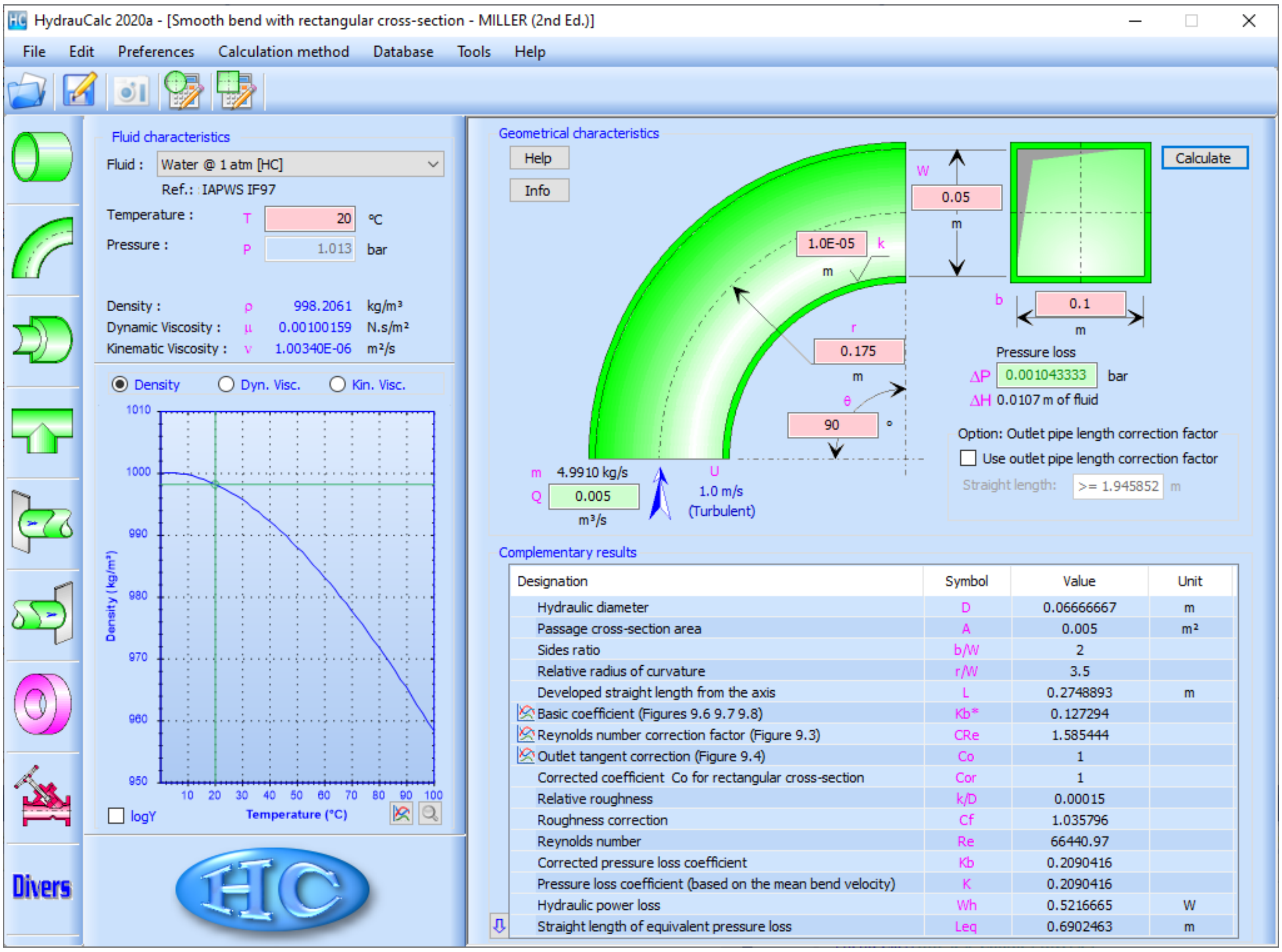
Validity range:

- turbulent flow regime ($Re \geq 10^4$)
- stabilized flow upstream bend
- curvature angle: between 10° and 180°
- relative radius of curvature 'r/W': between 0.5 and 10

- sides ratio 'b/W': between 0.5 and 2

  note: for any sides ratio 'b/W' less than 0.5, the resistance coefficients K_b^* are obtained by linear extrapolation from the values of K_b^* calculated for sides ratios of 0.5 and 1.
  for any sides ratio 'b/W' greater than 0.5 and 2, the resistance coefficients K_b^* are obtained by linear extrapolation from the values of K_b^* calculated for sides ratios of 0.5 and 1.

Example of application:



References:

[1] Internal Flow System, Second Edition, D.S. Miller

© François Corre 2020