Use of IDF Curves – Design of a roof drainage system

Your engineering firm is currently planning the construction of a residential apartment building in Davos, Switzerland. Your task is to design the roof drainage system of the building and particularly to estimate the diameter of: (a) the vertical leaders, (b) the vertical drains and (c) the horizontal drainpipes. A general layout of a roof drainage system is provided in Figure 1, whereas Figure 2 shows a schematic diagram of a roof drainage system. Based on the local regulations, the accepted level of risk for single buildings is the 50-year flood (i.e. flood occurring on average once in 50 years) of 10-min duration. The local rainfall intensity-duration-frequency curve (IDF curve) is provided in Figure 3.

The roof covers an area, A, of 7440 m^2, the slope of the horizontal pipes leading from the vertical leaders to the wall (type a), S_1, is equal to 0.010 m/m and the slope of the horizontal pipes draining the interior leaders in the interior walls (type b), S_2, is equal to 0.042 m/m.

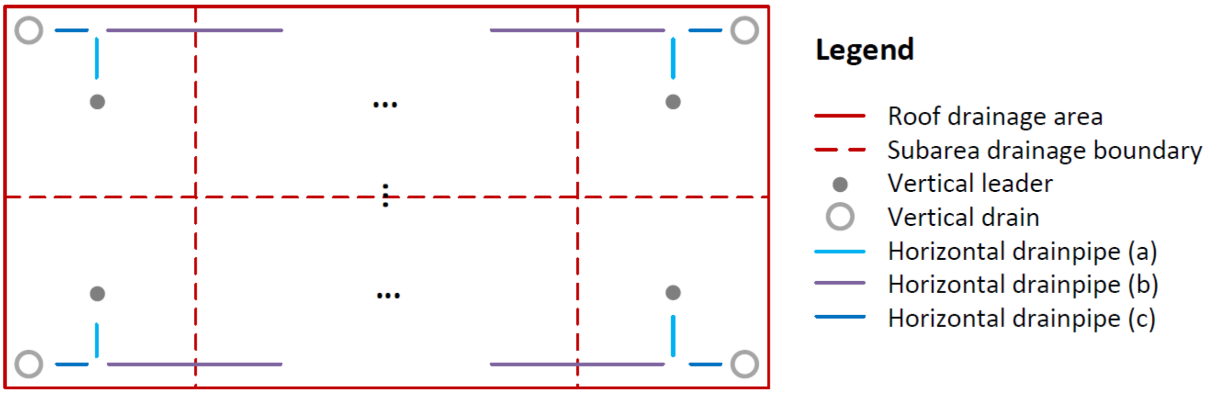


Figure 1: General layout of a roof drainage system

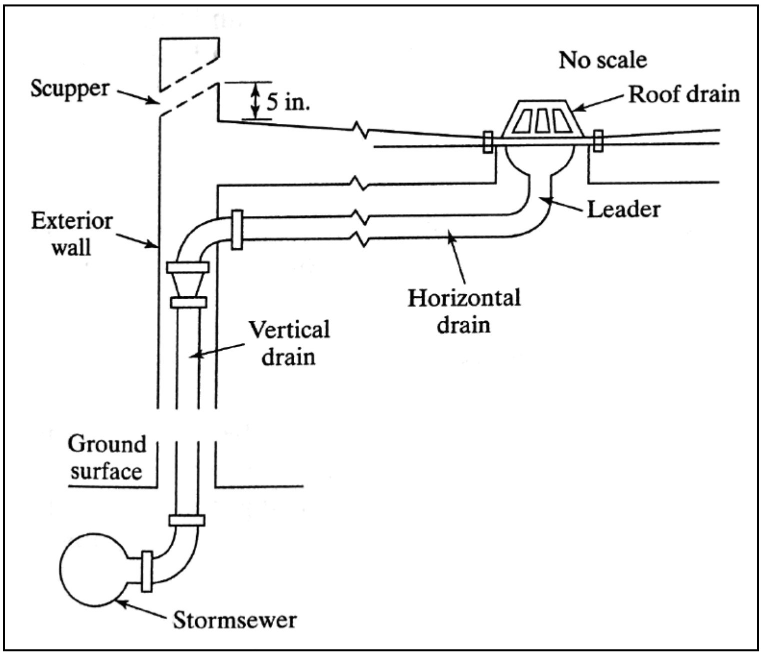


Figure 2: Schematic diagram of the roof drainage system

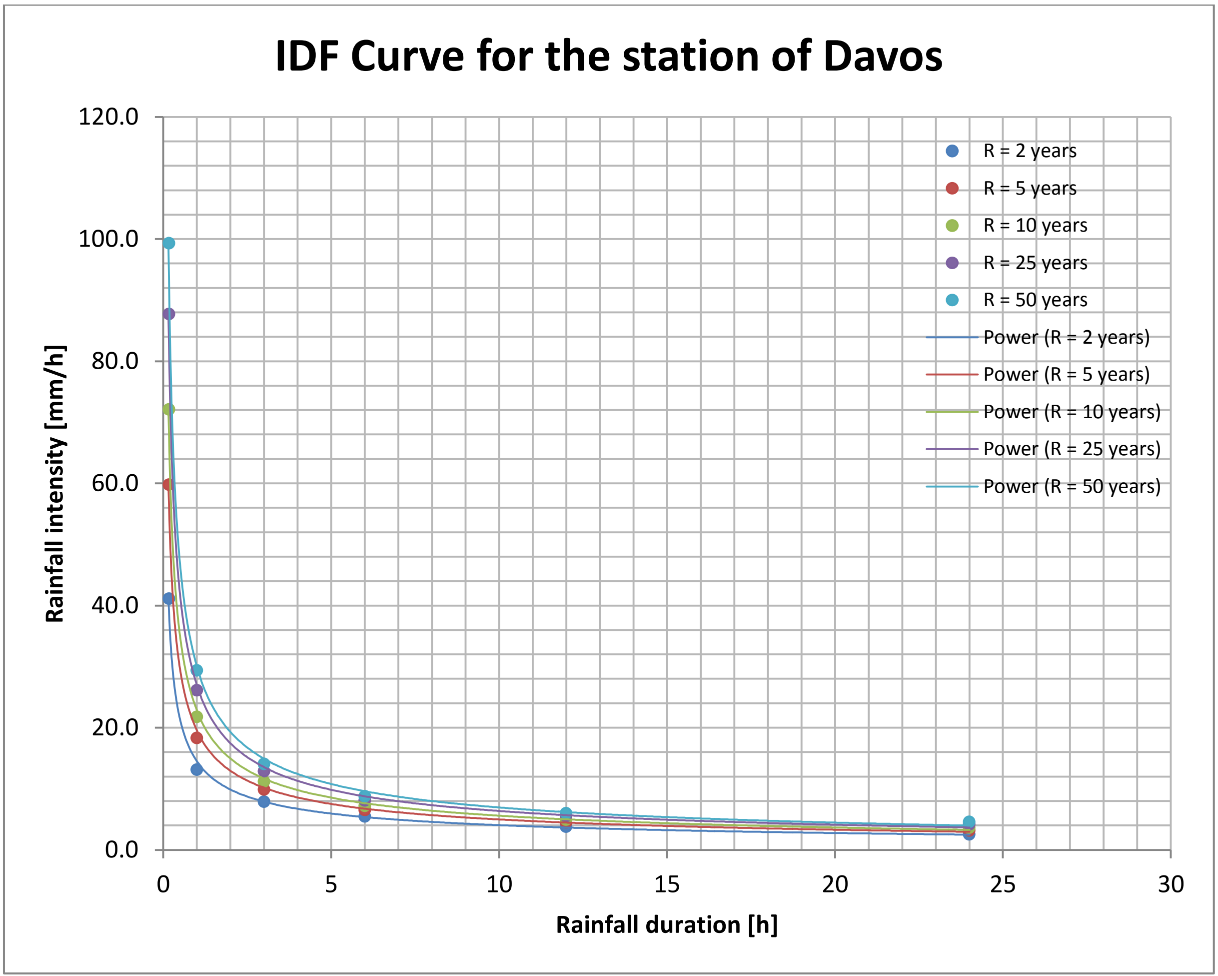


Figure 3: Rainfall intensity-duration-frequency curve for the station of Davos

Literature

Chow, V.T., Maidment, D.R. and Mays, L.W. (1988). Applied Hydrology, New York. McGraw-Hill.
McCuen, R.H. (2017). Hydrologic analysis and design. Fourth Edition. Department of Civil and Environmental Engineering. University of Maryland. Boston. Pearson.

Summary of the solution procedure

The first step of the design procedure is to select a layout for the roof drainage system determining the required number of vertical leaders. Next, the design rainfall intensity is to be estimated based on the IDF curve and the drainage regulations (i.e. estimation of the rainfall intensity for a specific hazard frequency and runoff concentration time). Once the roof drainage system layout and the design rainfall intensity have been estimated, the rational method, that will be discussed in detail in a following lecture on Flood Frequency Analysis, can be used to estimate the design discharge entering the horizontal pipes. The horizontal pipes' diameter required to carry this discharge can be calculated by the Manning's equation assuming that the pipes are flowing full under gravity but are not pressurized. The diameter of the vertical leaders and drains may be estimated using the provided empirical equation.

Additional remarks and assumptions

- One vertical leader should be used per 930 m^2 of roof area
- The design rainfall intensity is obtained from the local IDF curve
- Pipe's flow is gravity driven but is not pressurized, so that the pipe capacity can be calculated by means of the Manning's equation for open channel flow
- The friction slope is set equal to the bed slope of the pipe
- The Manning's roughness coefficient n is 0.015 for all horizontal drainpipes
- The estimated diameter values should be rounded up to the next larger commercially available size
- The following pipe diameters in [mm] are available for roof drains: 50, 100, 150, 200, 250, 300, 400, and 450

Collection of formulas

- Rational Method

$$Q = C \cdot i \cdot A \qquad (1)$$

- Pipe Capacity based on the Manning's Equation

$$d = \left(\frac{3.21 \cdot Q_d \cdot n}{S^{0.5}}\right)^{0.375} \qquad (2)$$

- Vertical leader and drain diameter (empirical equation)

$$d' = 0.573 \cdot Q_d^{0.375} \qquad (3)$$

where: A is the drainage area [m^2]

C is the runoff coefficient for the drainage area A

d is the pipe diameter [m]

d' is the diameter of both vertical leaders and drains [m]

i is the design rainfall intensity [mm/h]

n is the Manning's roughness coefficient

Q is the peak discharge rate [m^3/s]

Q_d is the design capacity per pipe [m^3/s]

S is the slope of the pipe [m/m]

Appendix

Table A 1: Runoff coefficients for use in the rational method (Chow et al., 1988)

	Return Period (years)						
Character of surface	**2**	**5**	**10**	**25**	**50**	**100**	**500**
Developed							
Asphaltic	0.73	0.77	0.81	0.86	0.90	0.95	1.00
Concrete/roof	0.75	0.80	0.83	0.88	0.92	0.97	1.00
Grass areas (lawns, parks, etc.)							
Poor condition (grass cover less than 50% of the area)							
Flat, 0–2%	0.32	0.34	0.37	0.40	0.44	0.47	0.58
Average, 2–7%	0.37	0.40	0.43	0.46	0.49	0.53	0.61
Steep, over 7%	0.40	0.43	0.45	0.49	0.52	0.55	0.62
Fair condition (grass cover on 50% to 75% of the area)							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Good condition (grass cover larger than 75% of the area)							
Flat, 0–2%	0.21	0.23	0.25	0.29	0.32	0.36	0.49
Average, 2–7%	0.29	0.32	0.35	0.39	0.42	0.46	0.56
Steep, over 7%	0.34	0.37	0.40	0.44	0.47	0.51	0.58
Undeveloped							
Cultivated Land							
Flat, 0–2%	0.31	0.34	0.36	0.40	0.43	0.47	0.57
Average, 2–7%	0.35	0.38	0.41	0.44	0.48	0.51	0.60
Steep, over 7%	0.39	0.42	0.44	0.48	0.51	0.54	0.61
Pasture/Range							
Flat, 0–2%	0.25	0.28	0.30	0.34	0.37	0.41	0.53
Average, 2–7%	0.33	0.36	0.38	0.42	0.45	0.49	0.58
Steep, over 7%	0.37	0.40	0.42	0.46	0.49	0.53	0.60
Forest/Woodlands							
Flat, 0–2%	0.22	0.25	0.28	0.31	0.35	0.39	0.48
Average, 2–7%	0.31	0.34	0.36	0.40	0.43	0.47	0.56
Steep, over 7%	0.35	0.39	0.41	0.45	0.48	0.52	0.58

Suggested solution

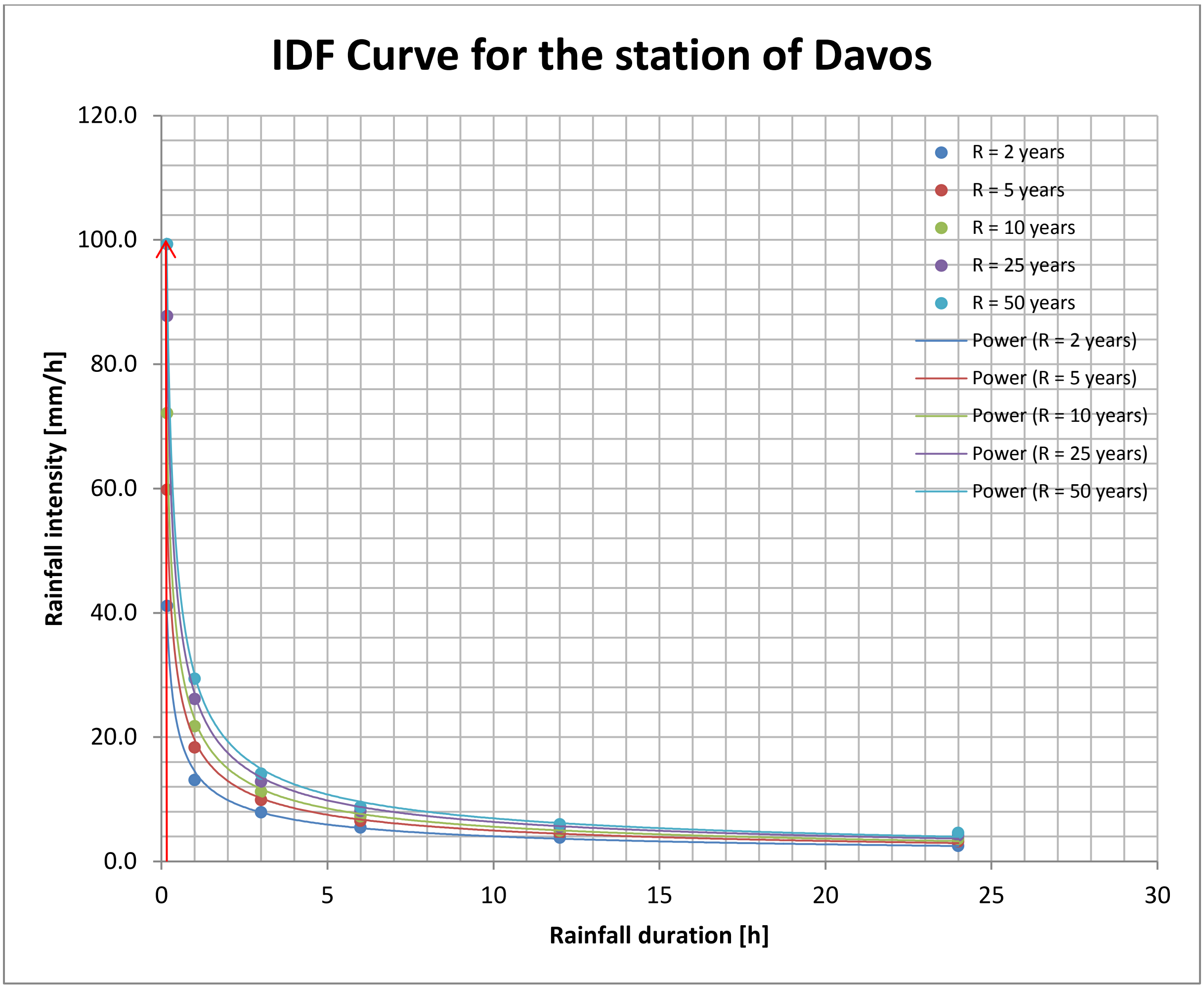
- **Estimation of the number of vertical leaders**

Provided that one vertical leader should be used per 930 m^2 of roof area and the rooftop covers an area of 7440 m^2, the number of leaders, n, may be estimated as follows:

$$n = \frac{\text{rooftop area}}{1 \text{ leader per } 930 \text{ m}^2} = \frac{7440 \text{ m}^2}{930 \text{ m}^2} = 8 \text{ vertical leaders}$$

- **Estimation of the design rainfall intensity**

The design rainfall intensity is obtained from the local IDF curve (Figure 3) and the local drainage regulations (i.e. duration and frequency of the rainfall). The local drainage regulations specify the following rainfall requirements: (a) a hazard frequency corresponding to 50-year return period and (b) a runoff concentration time of 10-min. Using the IDF curve provided in Figure 3, the corresponding rainfall intensity is computed as approximately 99.3 mm/h.



- **Estimation of the flow capacity per vertical leader**

The total peak discharge rate, Q, may be specified using the design rainfall intensity, i, and applying the rational method (Equation 1). The value of the runoff coefficient may be determined using Table A 1. For a rooftop area and a hazard frequency corresponding to 50-year return period, the runoff coefficient is equal to 0.92.

$$\mathrm{Q = C \cdot i \cdot A \Rightarrow Q\,[m^3/s] = 0.92 \cdot 99.3\,[mm/h] \cdot 7440\,[m^2] \cdot [10^{-3}\,m/1\,mm] \cdot [1\,h/3600\,s] \Rightarrow}$$

$$\mathrm{Q\ = 0.19\,[m^3/s]}$$

To determine the design flow capacity per vertical leader, Q_d, one has to divide the total peak discharge rate, Q, by the number of vertical leaders, n. It is assumed that the total peak discharge rate is equally distributed to each vertical leader.

$$\mathrm{Q_d = Q/n \Rightarrow Q_d\,[m^3/s] = 0.19\,[m^3/s]/8\,[leaders] \Rightarrow Q_d = 0.024\,[m^3/s]}$$

- **Design of the roof drainage system**

The last step of the design procedure is to compute the size of the vertical leaders, the vertical drains, and the horizontal drainpipes. As observed in the layout of the roof drainage system (Figure 1) and estimated above, the system comprises of 8 vertical leaders and 4 vertical drains. Each vertical drain drains out two vertical leaders. Regarding the horizontal drainpipes, three different types exist: (a) 8 horizontal pipes leading from the vertical leaders to the wall, (b) 4 interior horizontal pipes, and (c) 4 horizontal pipes in the sections where the horizontal pipes of the interior leaders connect with the pipes of the exterior leaders.

- **Vertical leaders**

The diameter of both vertical leaders and drains may be determined applying the empirical equation (3).

The diameter of each vertical leader is as follows:

$$\mathrm{d' = 0.573 \cdot Q_d^{0.375} \Rightarrow d'[m] = 0.573 \cdot 0.024\,[m^3/s]^{0.375} \Rightarrow d' = 0.142\,[m]}$$

Given the available commercial diameters, a **150-mm leader** is chosen.

- **Vertical drains**

The diameter of each vertical drain is as follows:

$$\mathrm{d' = 0.573 \cdot Q_d^{0.375} \Rightarrow d'[m] = 0.573 \cdot 0.048\,[m^3/s]^{0.375} \Rightarrow d' = 0.183\,[m]}$$

Given the available commercial diameters, a **200-mm drain** is chosen.

In this case, the flow capacity per vertical drain is twice the flow capacity per vertical leader as calculated above because each vertical drain drains out two vertical leaders.

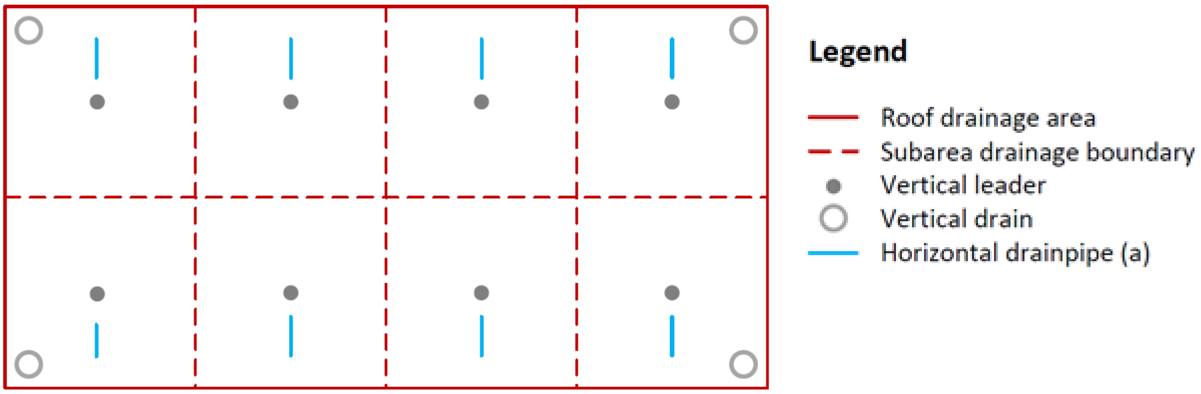
– **Horizontal drainpipes**

The diameter of horizontal pipes of any type may be determined applying the equation (2).

The diameter of each horizontal pipe leading from the vertical leaders to the wall (type a) is as follows:

$$d = \left(\frac{3.21 \cdot Q_d \cdot n}{S_1^{\,0.5}}\right)^{0.375} \Rightarrow d\,[m] = \left(\frac{3.21 \cdot 0.024\,[m^3/s] \cdot 0.015}{0.010^{0.5}}\right)^{0.375} \Rightarrow d = 0.188\,[m]$$

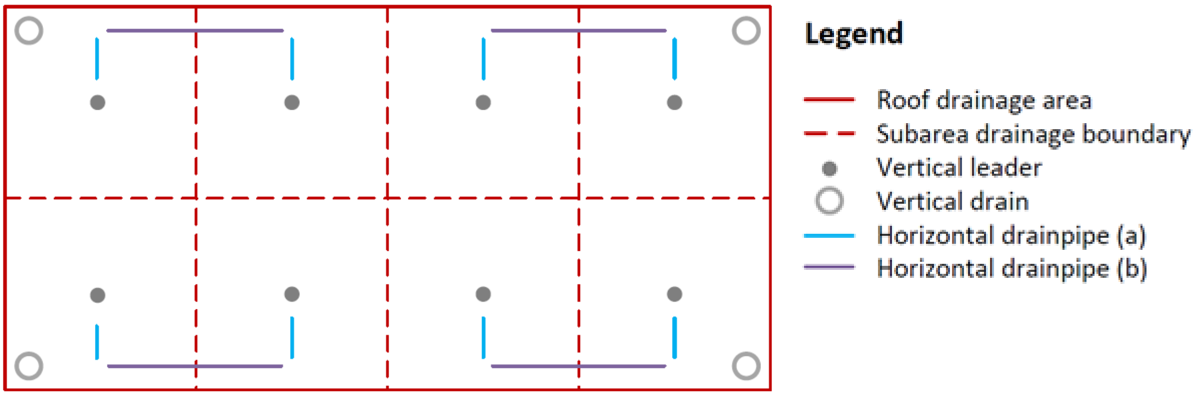
Given the available commercial diameters, a **200-mm horizontal pipe** is chosen.



The diameter of each interior horizontal pipe (type b) is as follows:

$$d = \left(\frac{3.21 \cdot Q_d \cdot n}{S_2^{\,0.5}}\right)^{0.375} \Rightarrow d\,[m] = \left(\frac{3.21 \cdot 0.024\,[m^3/s] \cdot 0.015}{0.042^{0.5}}\right)^{0.375} \Rightarrow d = 0.143\,[m]$$

Given the available commercial diameters, a **150-mm horizontal pipe** is chosen.



The diameter of each horizontal pipe in the sections where the horizontal pipes of the interior leaders connect with the pipes of the exterior leaders (type c) is as follows:

$$d = \left(\frac{3.21 \cdot Q_d \cdot n}{S_2^{\,0.5}}\right)^{0.375} \Rightarrow d\,[m] = \left(\frac{3.21 \cdot 0.048\,[m^3/s] \cdot 0.015}{0.042^{0.5}}\right)^{0.375} \Rightarrow d = 0.186\,[m]$$

Given the available commercial diameters, a **200-mm horizontal pipe** is chosen.

In this case, the flow capacity is twice the flow capacity per drain as calculated above because each pipe drains out two vertical leaders. A slope of 0.042 m/m is assumed as well.