7. Fall manhole

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7. Fall manhole

Goals of this chapter

To know

- the concepts applied on steep topographies, with their application range
- the design procedure of the different fall manholes
- to identify phenomena related to fall manholes, i.e. to know their weak points

7. Fall manhole

Context

Literature

W.H. Hager (1999). *Wastewater Hydraulics*, Springer, Berlin
VSA (1993). *Sonderbauwerke in Kanalisationen*
SIA (1980). *Sonderbauwerke der Kanalisationstechnik* I
Séminaire VSA/EPFL (2013). *Hydraulique des canalisations*

7.1 Introduction

7.1 Introduction

Example

What is your interpretation of these “drop shafts”?

7.1 Introduction

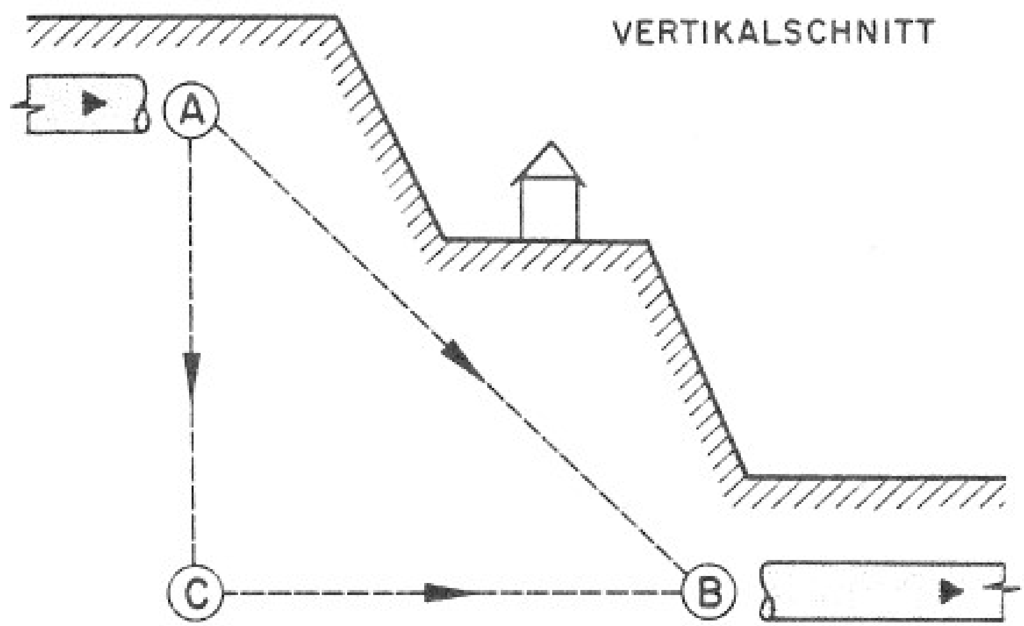
Steep topography

- Steep conduits with fast flow and air transport requiring large diameters, hydraulic jump downstream of (B)
- Mild slopes with fall manholes, for step-type topographies

Fall manhole: Elevation difference with energy dissipation

Two types

- Drop manhole
- Vortex drop shaft



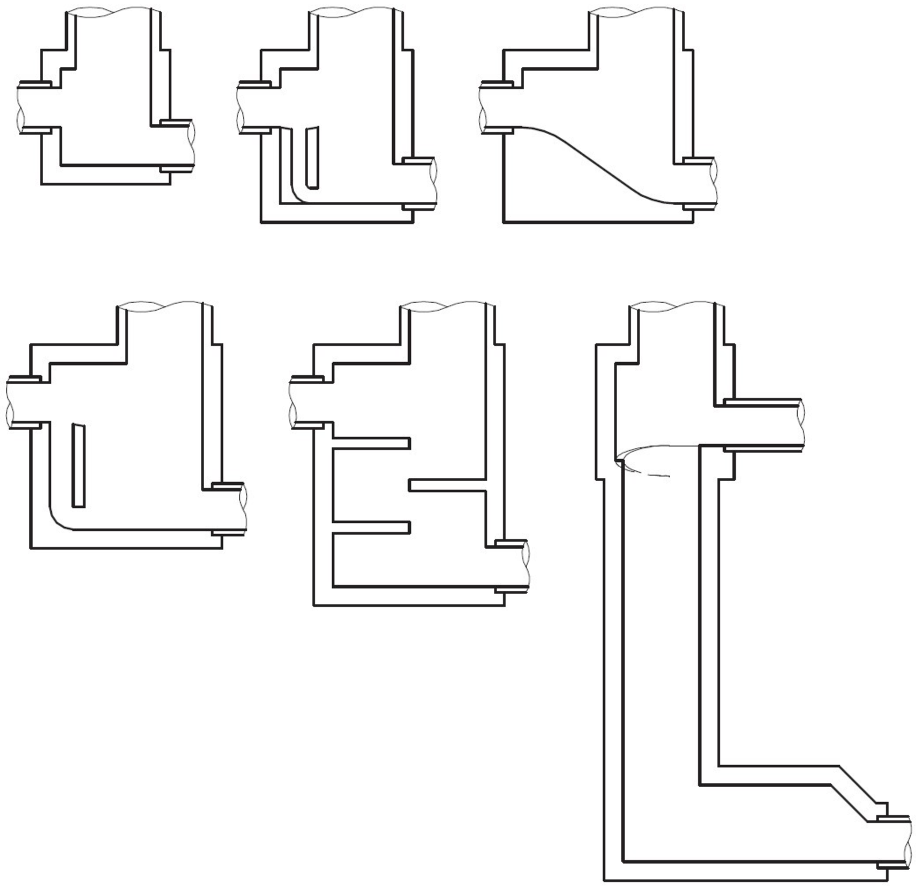
7.1 Introduction

For "small" applications use standard manhole (prefabricated)

7.1 Introduction

Overview of frequent types

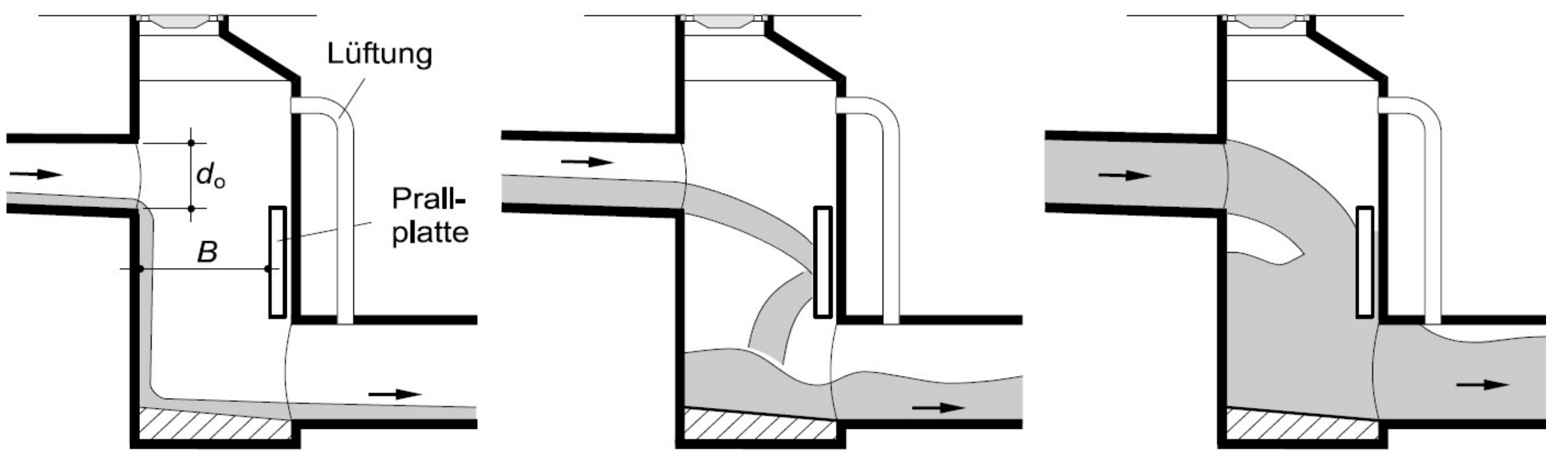
- Drop manhole without inserts
- Drop manhole with drop pipe or chute
- Drop manhole with deflector: vertical wall or baffle drop shaft
- Vortex drop shaft



7.1 Introduction

Drop manhole without inserts (DWA A112)

Better subcritical approach flow
$H > D_o$ and $H < 5$ m
$B > 1.5 .. 2D_o$ and $B > 1.5$ m
$D_o < 0.8$ m
downstream conduit $y_{uM} < 0.7$

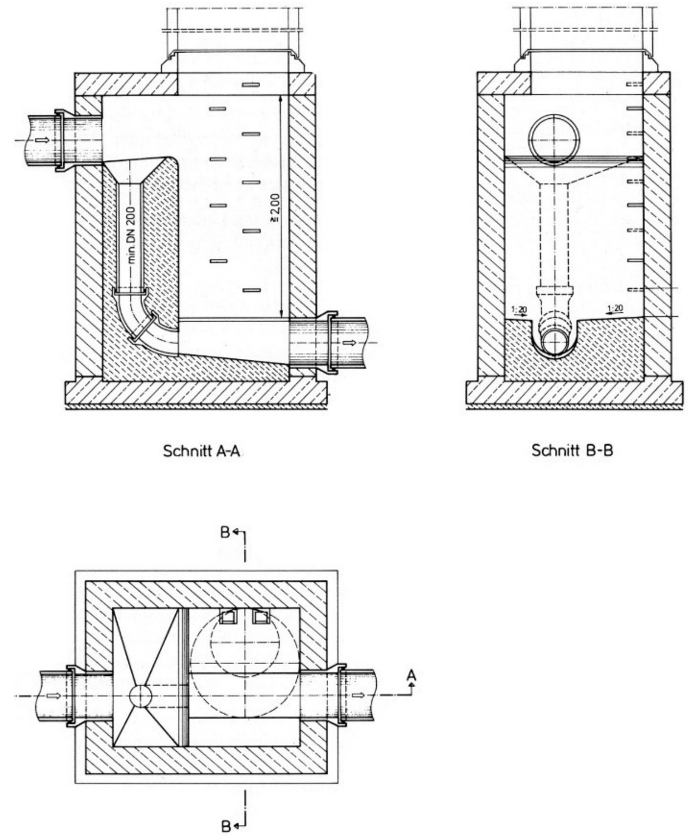


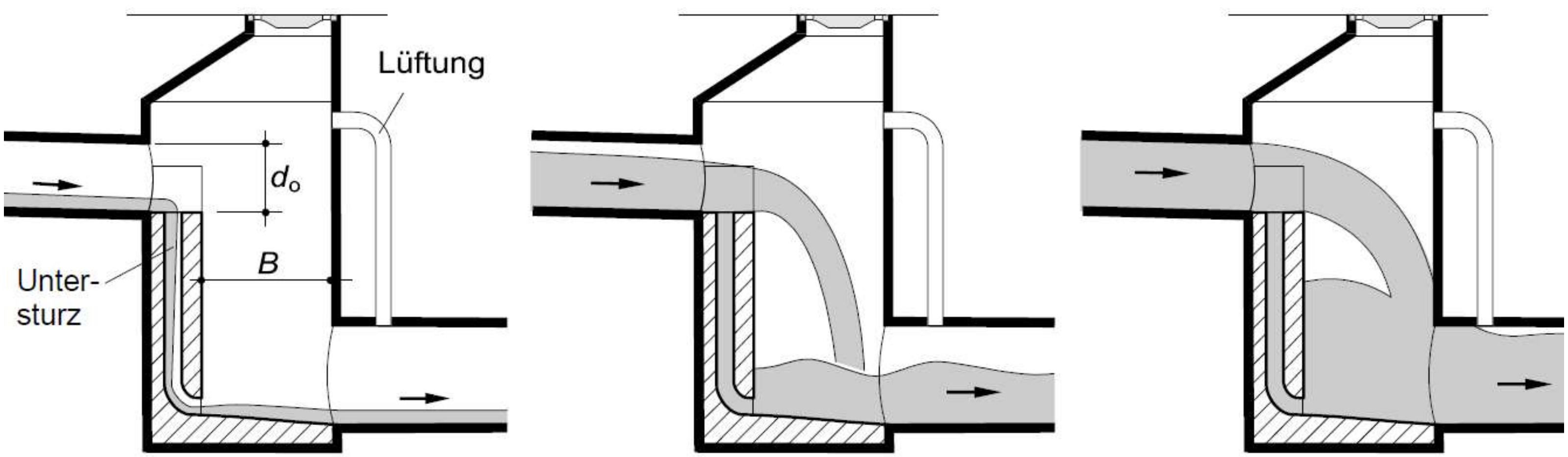
7.1 Introduction

Drop manhole with drop pipe (DWA A112)

Better subcritical approach flow
Q_M<0.5 m³/s
H<5 m
D_o<0.4 .. 0.8 m
D_s≥0.2 m
B>2D_o et B>1.5 m
downstream conduit y_{uM}<0.7

$$D_s = \sqrt[5]{\frac{Q^2}{g}}$$

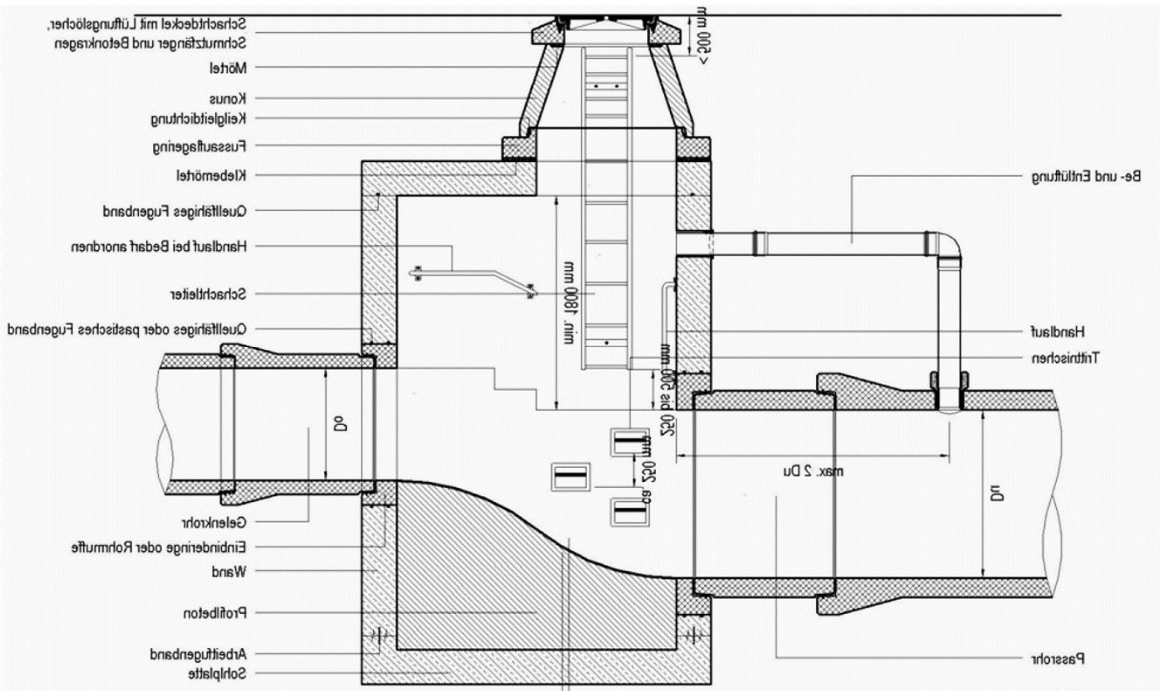




7.1 Introduction

Drop manhole with chute (DWA A112, CAS Siedlungsentwässerung)

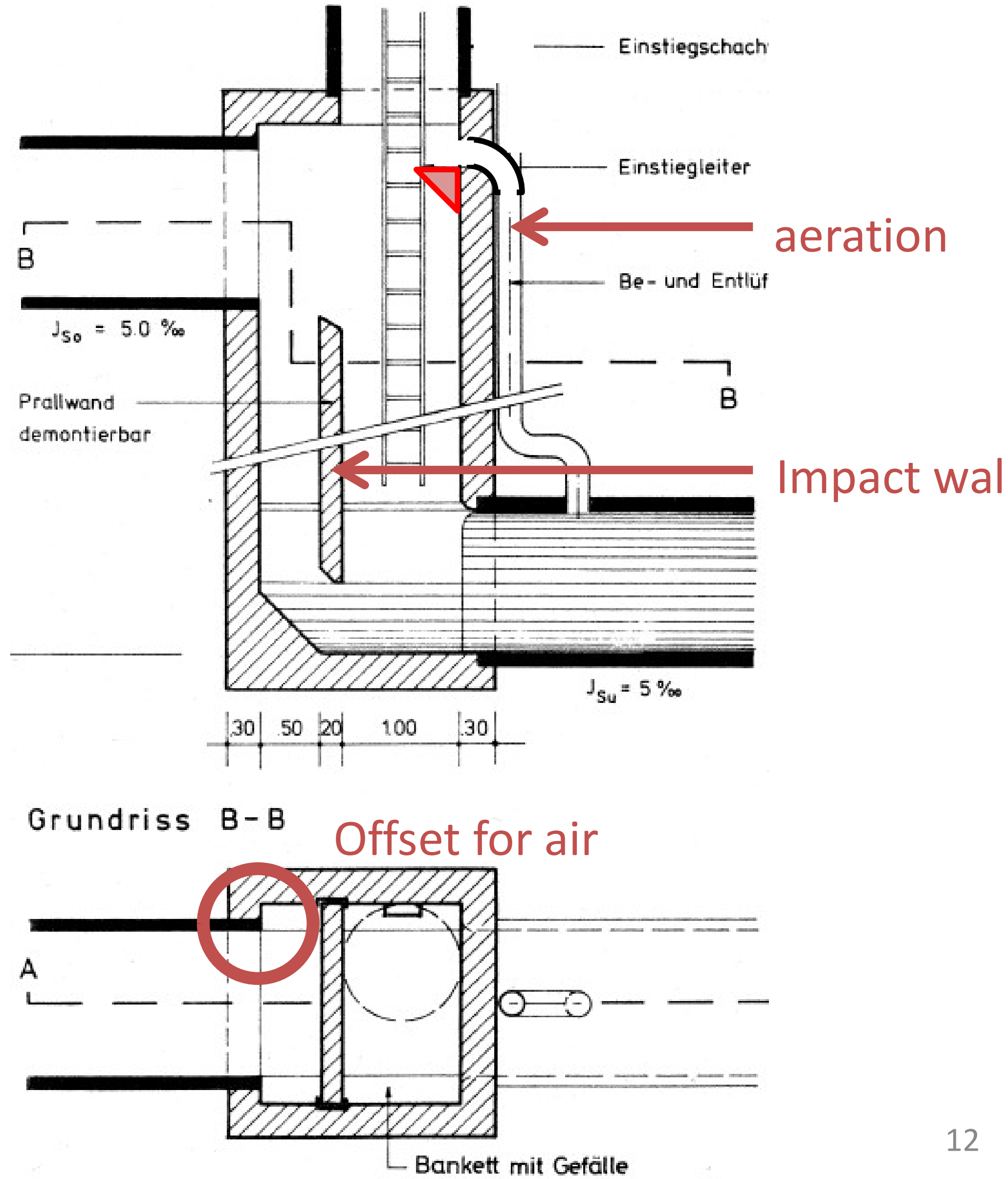
- For large *Q* and small *H*
- Jet trajectory must follow invert at least up to $3Q_m$ (see chapter 7.2)
- Smooth versus stepped invert
- Hydraulic jump in downstream conduit (large *D*, aeration)
- Length > $2D_o$
- downstream conduit y_{uM}<0.75



7.1 Introduction

Drop manhole with vertical deflector (Hager 2010)

H<10 m
D_o>0.4 m
0.5 m^3/s<Q_M<2.5 m^3/s

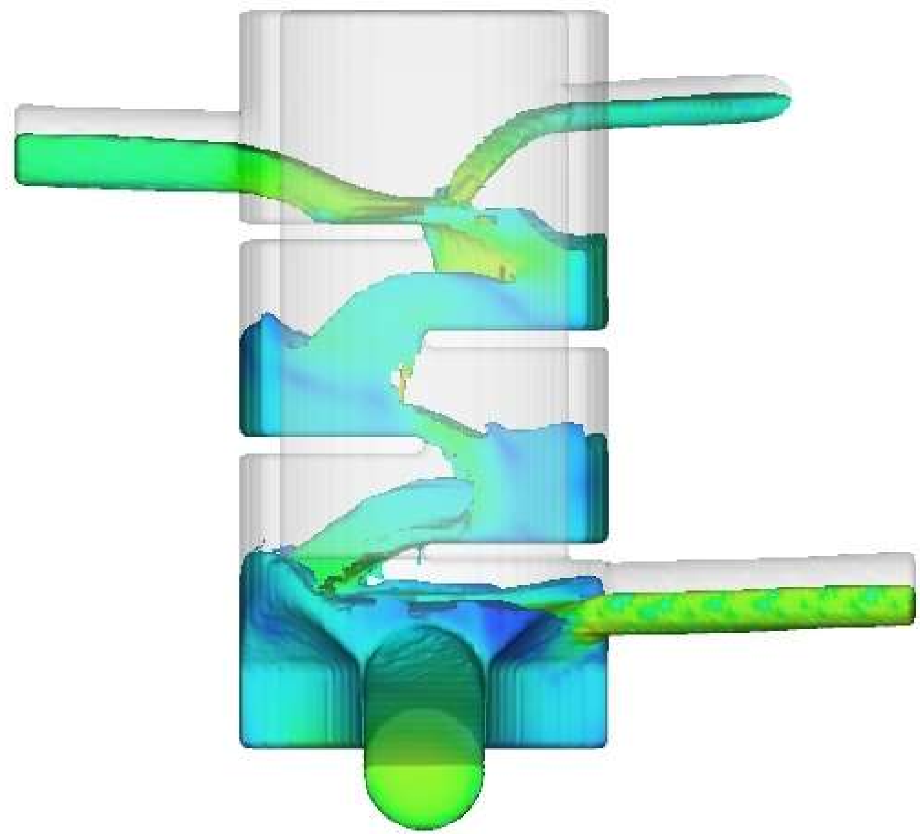


7.1 Introduction

Drop manhole with horizontal deflectors (HEIA-FR)

H<10…20 m (70 m ?)
Q_M<13 m^3/s (?)

- connection of various branches at every elevation possible
- Large shaft diameter

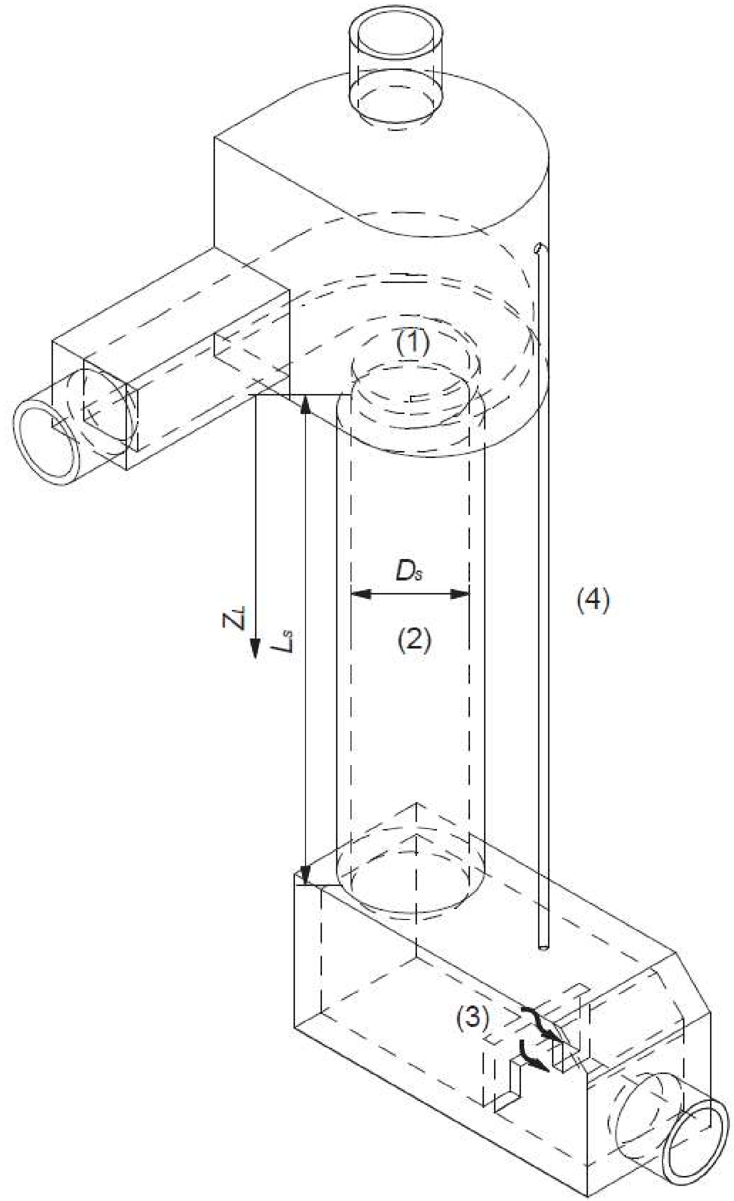


7.1 Introduction

Vortex drop shaft (Hager 2010)

20<H<120 m (?)
Q_M<20 m^3/s (?)

- separates water and air (annular flow in shaft)
- Dissipates energy
- Kellenberger (1.5<F<10)
- Drioli (F<0.7)



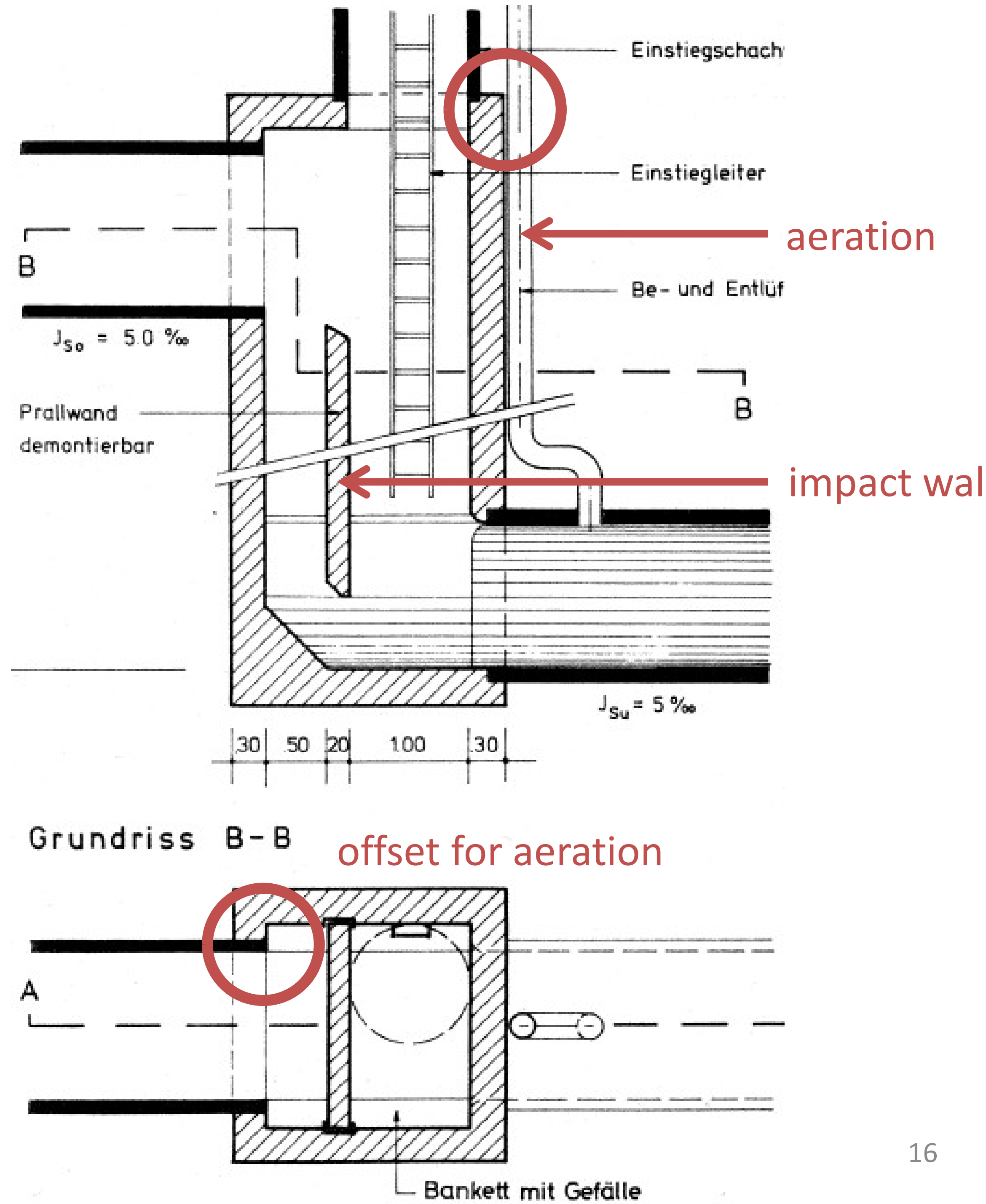
7.2 Drop manhole with vertical deflector

7.2 Drop manhole with vertical deflector

SIA

H<7 (10) m
D_o>0.4 m
0.5 m³/s<Q_M<2.5 m³/s

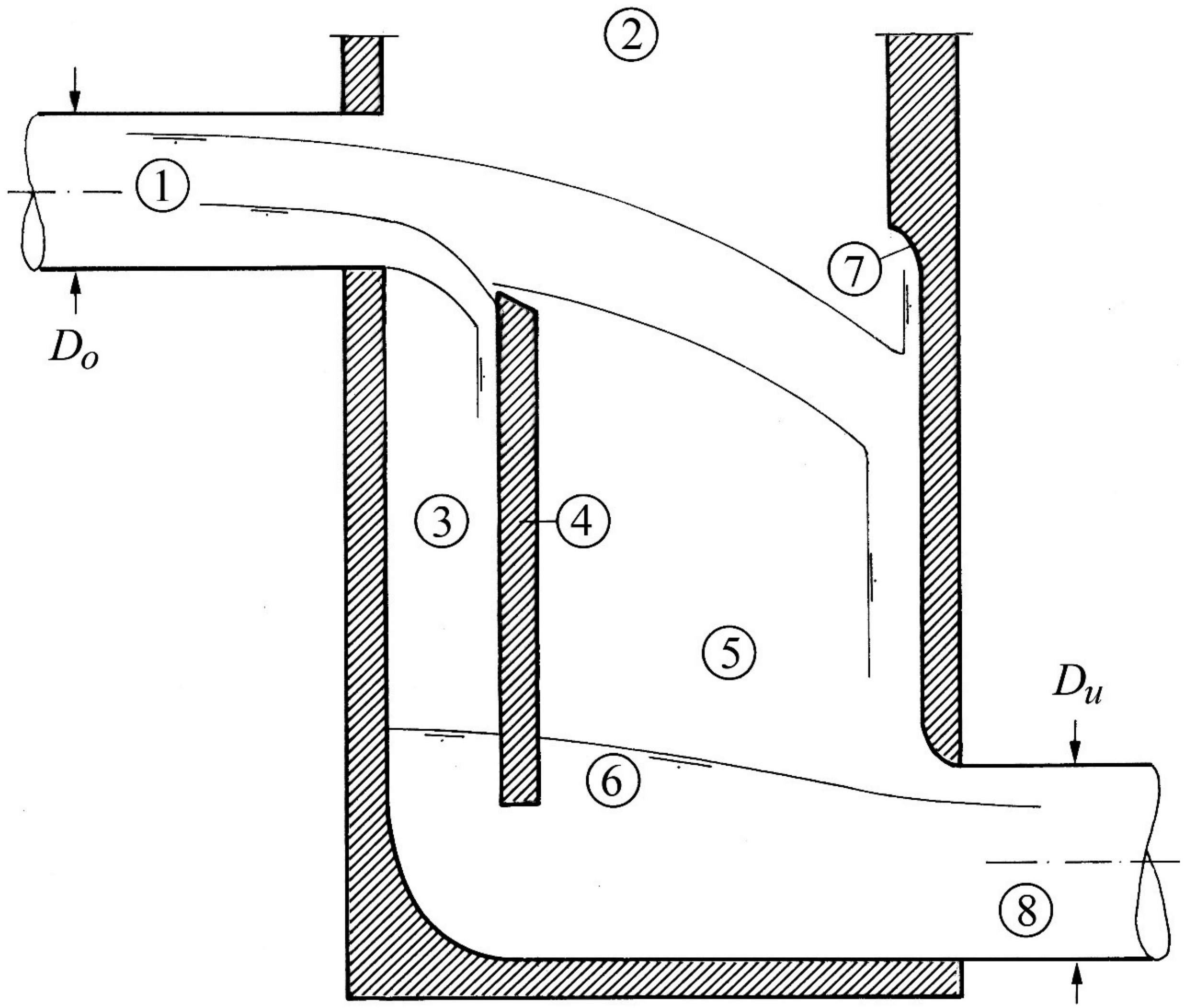
- Concentrate wastewater (hygiene, noise)
- “chaotic” comportment of water for large discharges
- Mixture air-water flow at shaft toe
- Potentially abrasion at invert



7.2 Drop manhole with vertical deflector

Nomenclature

1. Inflow conduit
2. Access and aeration
3. Dry-weather bypass
4. Impact wall (movable)
5. Drop chamber for storm water
6. Water cushion
7. Impact nose
8. Outlet



7.2 Drop manhole with vertical deflector

- From 2 to 7…10 m drop height
- Approach flow sub- or super-critical
- Dry weather discharge via bypass (few spray, hygiene, noise and odor)
- Storm water drop for maximum discharge, with energy dissipation at back wall
- Aeration opening in cover plate and downstream conduit
- Strengthen invert with resistant material, as granite plates to inhibit erosion
- Jet impact areas equipped with demountable plates

Limit of drop height (otherwise poor hydraulic performance) to avoid

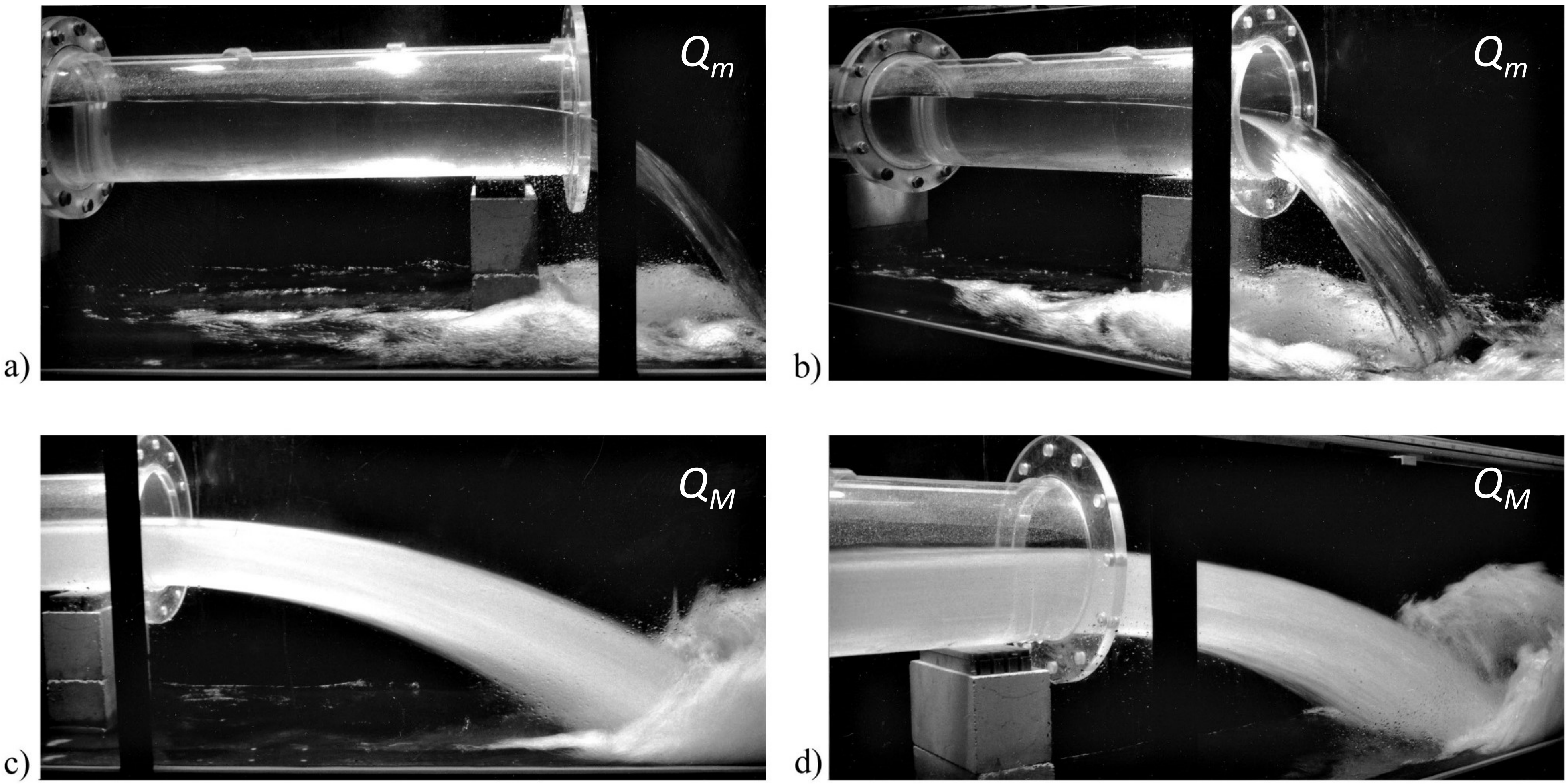
- excessive and “chaotic” air entrainment with pulsations and negative pressures
- air entrainment in downstream conduit, generating pulsations
- insufficient energy dissipation
- choking of lower branch
- noise emission

SIA, Hager

7.2 Drop manhole with vertical deflector

Approach flow pipe

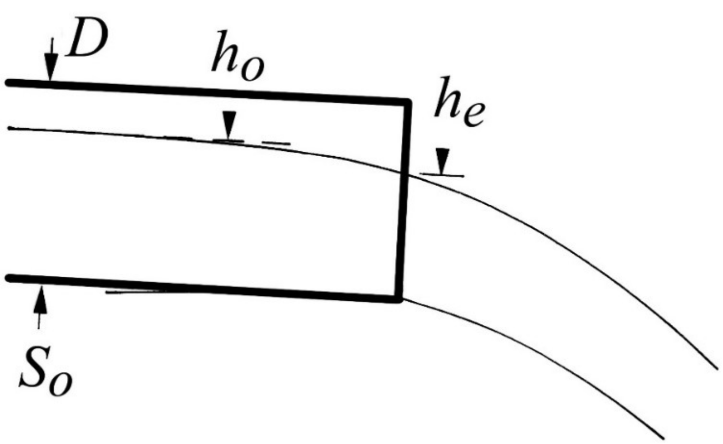
End overfall for circular profile (Hager 1999)



7.2 Drop manhole with vertical deflector

Approach flow pipe

- End-overfall for circular profile
- Terminal flow depth ratio, with h_o as uniform flow depth
- Take-off flow depth for jet trajectory computation



$$Y_e = \frac{h_e}{h_o} = \left(\frac{2\mathsf{F}_o^{\,2}}{1 + 2\mathsf{F}_o^{\,2}} \right)^{2/3}$$

7.2 Drop manhole with vertical deflector

Impact wall

Jet trajectories relevant for design

for Q_m ⇨ crest of impact wall above upper jet trajectory (divert entire dry-weather discharge)

for Q_M ⇨ crest of impact wall below lower jet trajectory (lower trajectory does not touch impact wall crest)

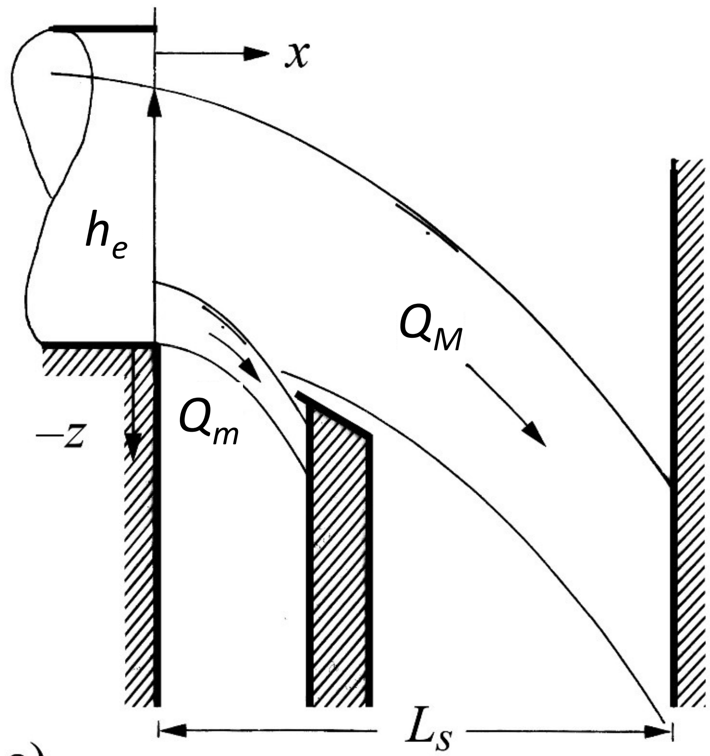
Lower jet trajectory ($0.8 < F_o < 8$)

$$Z = -\frac{1}{3}X - \frac{1}{4}X^2$$

Vertical jet thickness t

$$T = 1 + 0.06X$$

with $X = (x/h_o)F_o^{-0.8}$, $Z = z/h_o$ and $T = t/h_e$



a)

7.2 Drop manhole with vertical deflector

Outlet zone

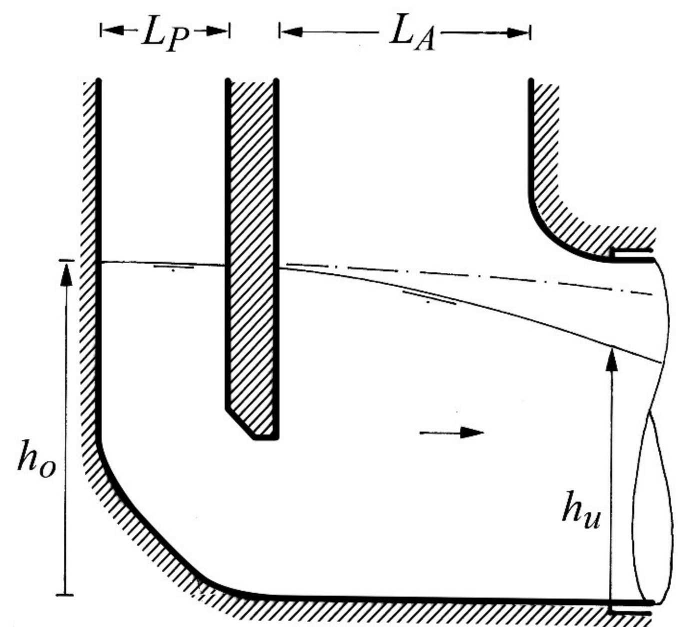
- Similar flow characteristics as side channel
- Provide sufficient aeration, $Q_A \leq 0.5 Q_W$
- Rounded upstream invert to avoid erosion

Design criteria: no chocking at outlet (to avoid gated outflow)

For super-critical downstream branch flow

$$y_o = \frac{h_o}{D_u} = \frac{5}{3}\left(\frac{Q}{\sqrt{g D_u^{\,5}}}\right)^{0.5}$$

Usually $h_o/D_u < 1.1$

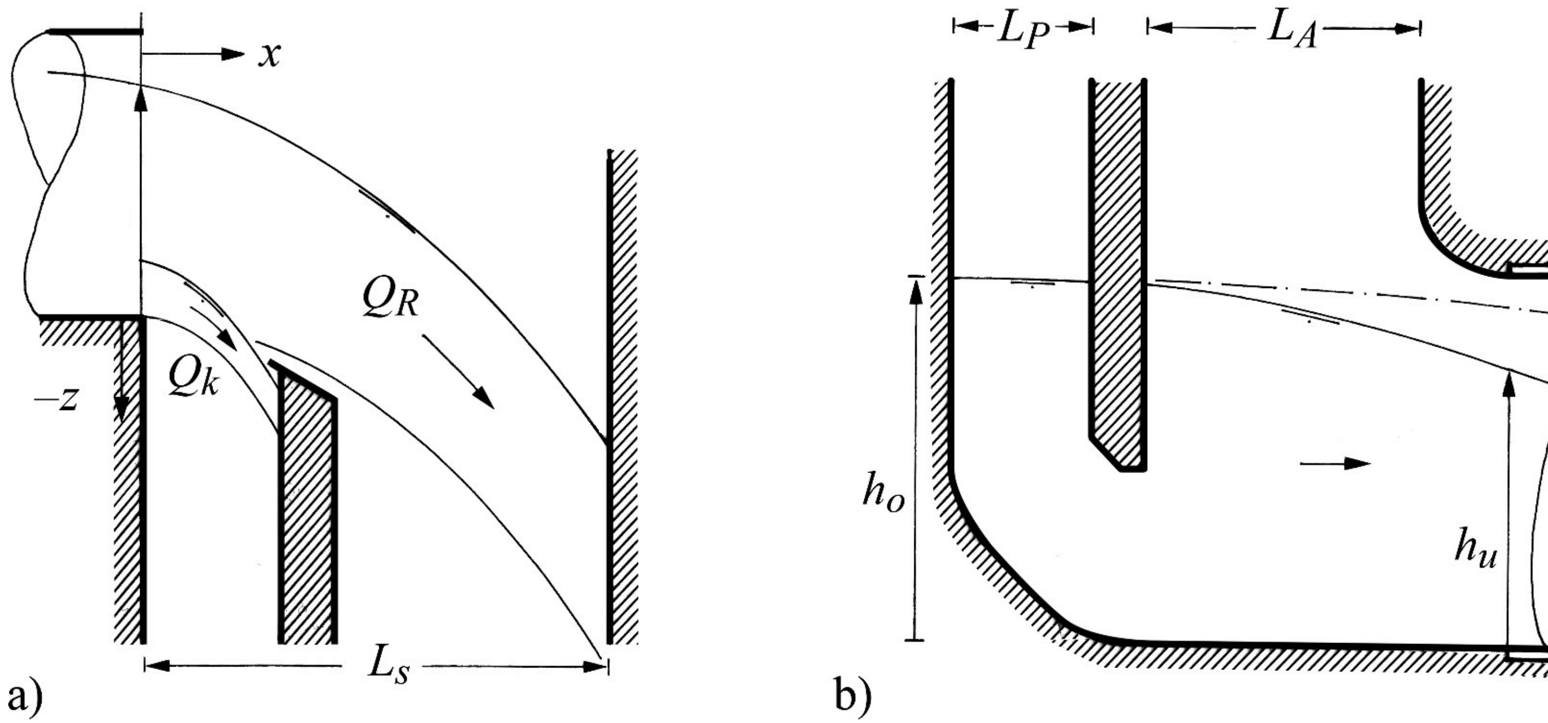


b)

7.2 Drop manhole with vertical deflector

Inspection and maintenance require minimum dimensions (SIA)

- Width of manhole ≥1 m
- By-pass length L_P≥0.5 m
- Drop chamber length L_A≥1 m
- Length of manhole L_S ≥2 m
- Thickness of impact wall <0.6 m
- Provide impact nose to avoid run-up



7.2 Drop manhole with vertical deflector

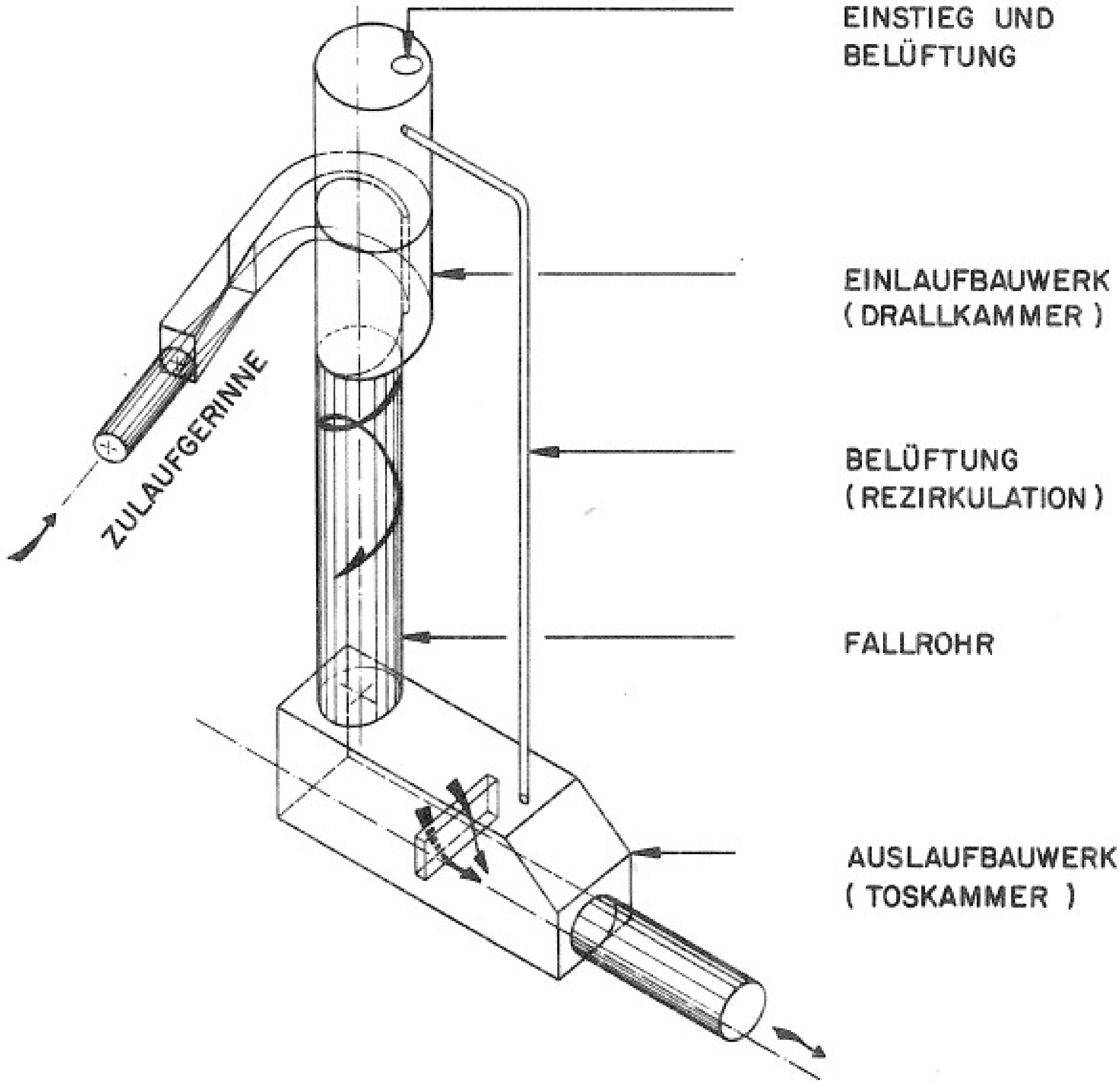
Example: Fall manhole with vertical deflector

Inflow conduit: S_o=1.2%, K=80 m$^{1/3}$/s, D_o=1.25 m, Q_m=0.16 m^3/s, Q_M=2.45 m^3/s
Drop height: H=6 m

7.3 Vortex drop shaft

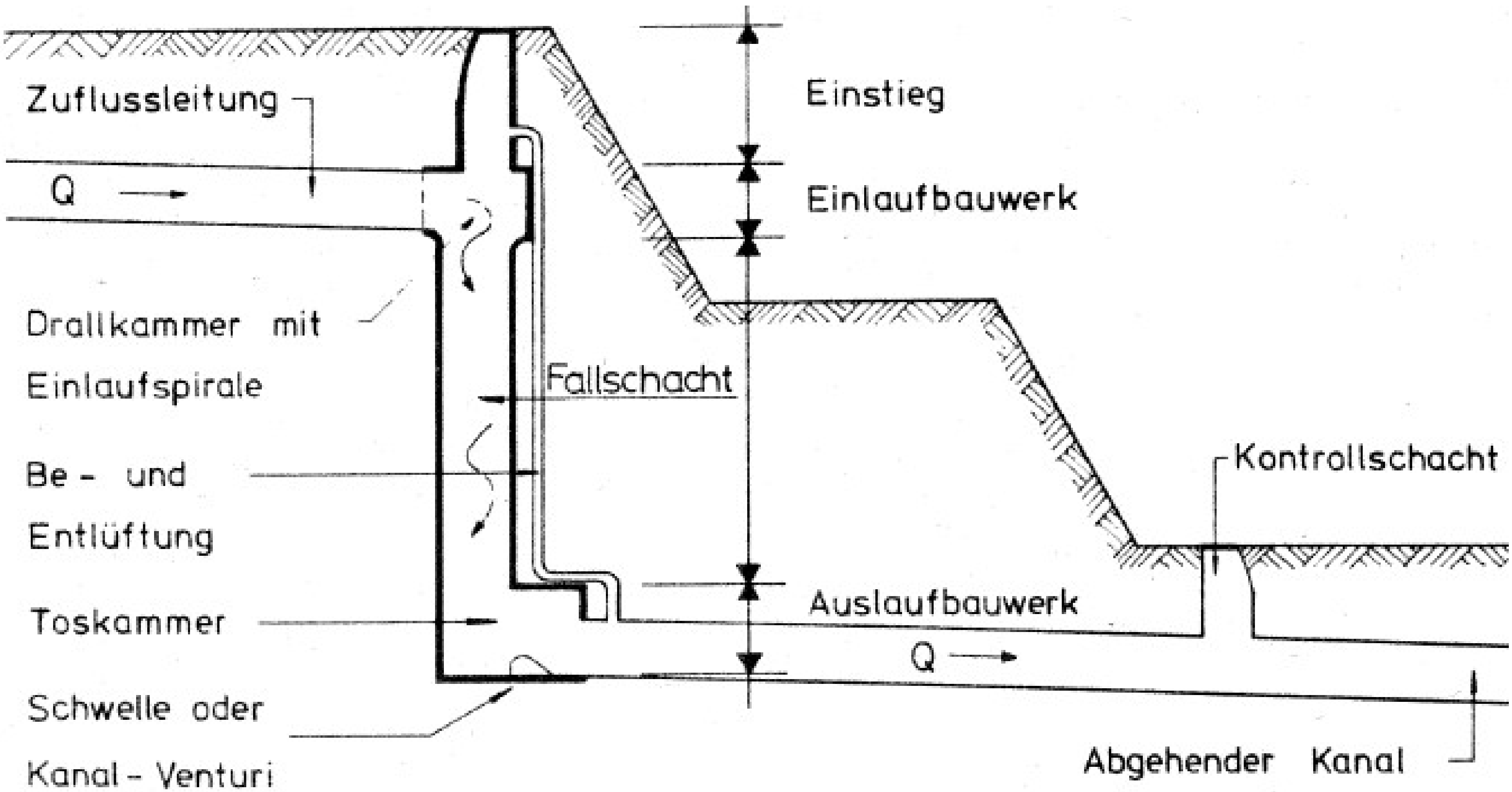
7.3 Vortex drop shaft

(VSA)



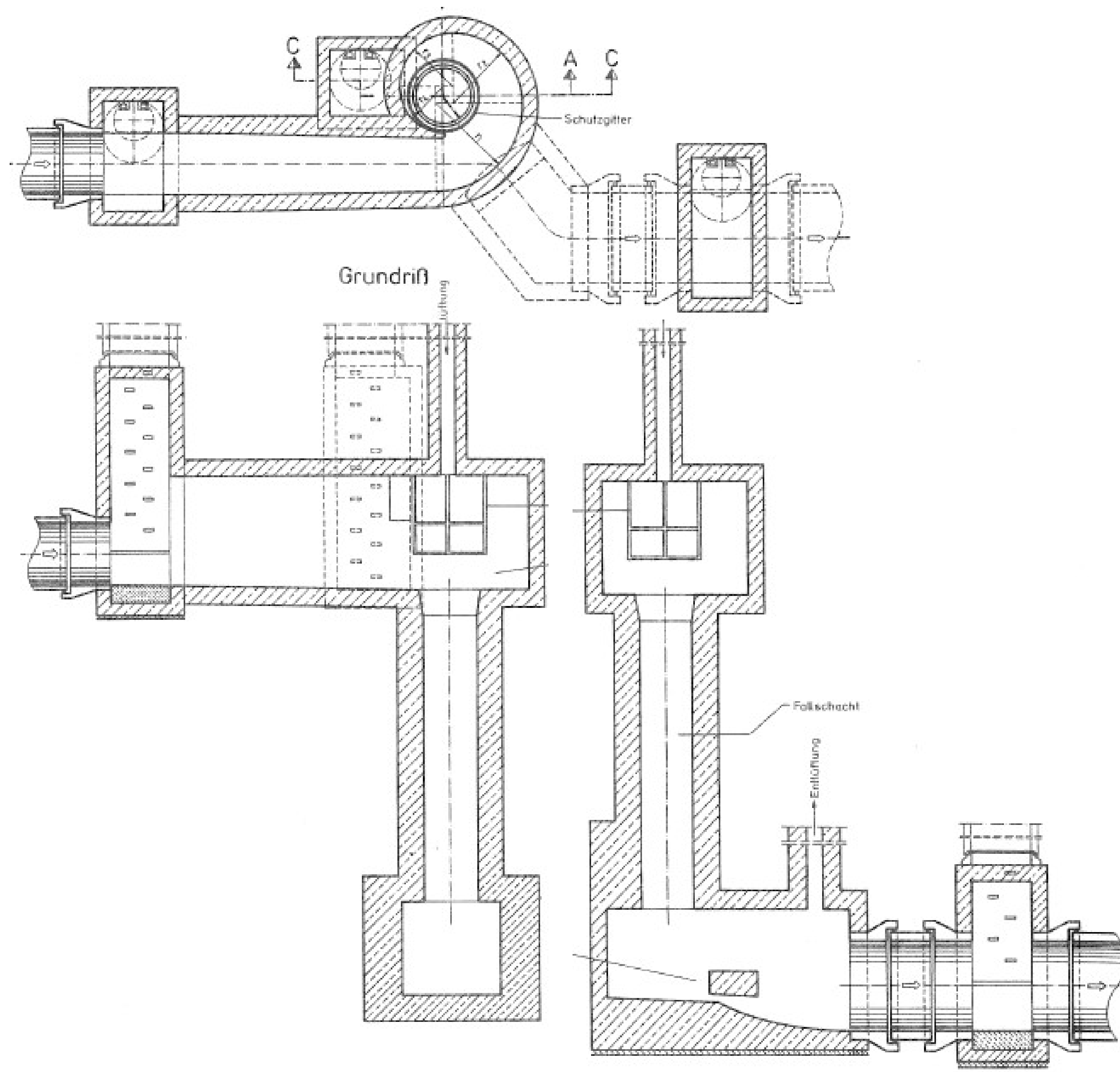
7.3 Vortex drop shaft

(SIA)



7.3 Vortex drop shaft

(ATV)



7.3 Vortex drop shaft

General

- Energy dissipation through shaft wall friction
- Small residual flow energy at foot of shaft
- Separates water and air flow
- Tangential inflow
- Water attached as spiral (annular) flow on shaft
- Use standard design (for modifications make model tests)

Limitations

- For drop heights from 10 m up to 100 m
- Approach flow Froude number either (F_o<0.7) or (1.5<F_o<10) for Q_M

Elements

- Inlet structure
- Vertical shaft
- Dissipation chamber

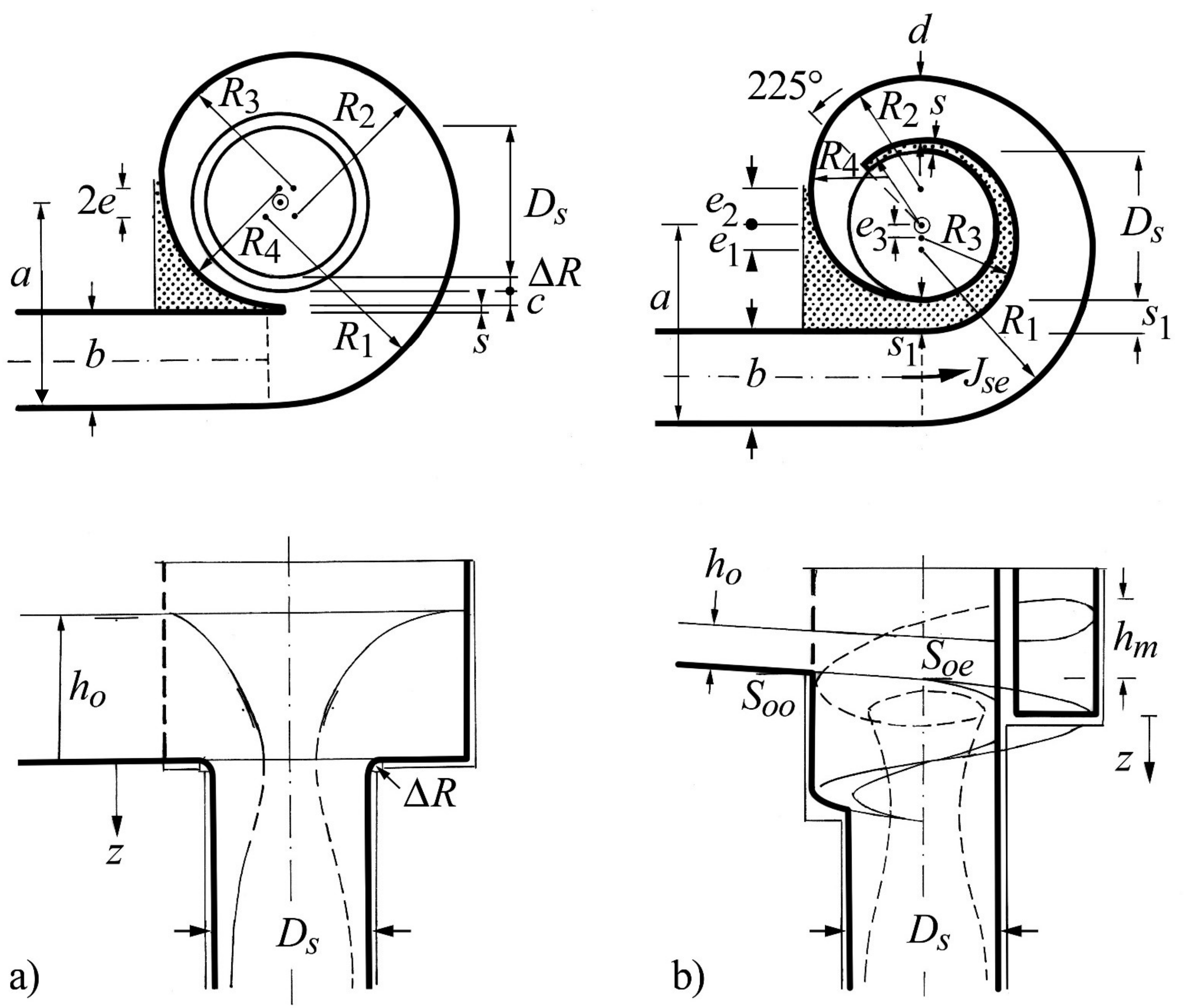
7.3 Vortex drop shaft

Inlet structure

Inflow channel
Rectangular and
>20*D* long
(not circular!)

Left
Sub-critical
inflow

Right
Super-critical
inflow



7.3 Vortex drop shaft

Inlet structure *sub-critical* inflow (Drioli 1969)

- $0.8<D_s/a<1$
- $\Delta R>D_s/6$

Parameters

a	distance shaft center to channel wall
b	inflow channel width
c	spiral width (10 to 40 cm)
e	eccentricity
s	thickness of guide wall (10 to 20 cm)

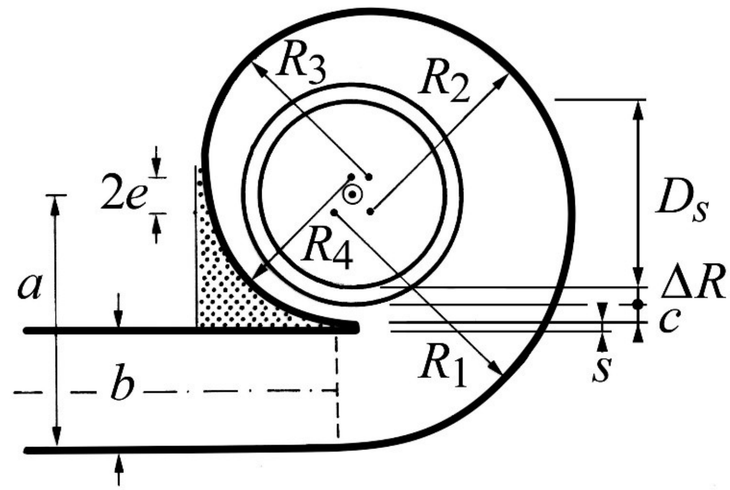
$a=R+\Delta R+b+c+s$ (mistake in Hager-Book)

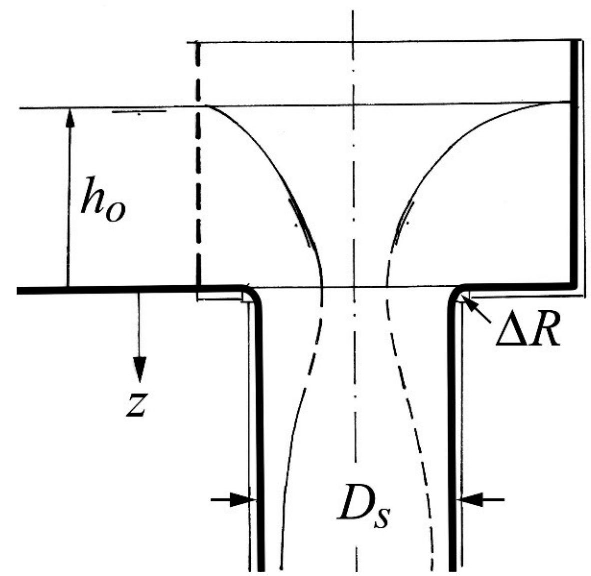
$e=(1/7)(b+s)$

$R_4=e+R+\Delta R+c$

$R_3=R_4+e$

$R_2=R_4+3e$, $R_1=R_4+5e$





7.3 Vortex drop shaft

Inlet structure *sub-critical* inflow (Drioli 1969)

Discharge - shaft diameter relation

$$Q_M = 4R^3\left(\frac{5g}{b}\right)^{1/2}$$

to avoid choking at inlet

Flow depth h_o? ($R=D_s/2$)

$$\frac{Q}{\left(\frac{gaR^5}{b}\right)^{1/2}} = \frac{\sqrt{2}h_o}{\left(\frac{aR}{b}\right)}$$

If $h_o > h_N$ ⇨ backwater ⇨ reduce slope or increase D_s of inflow conduit (choking)

7.3 Vortex drop shaft

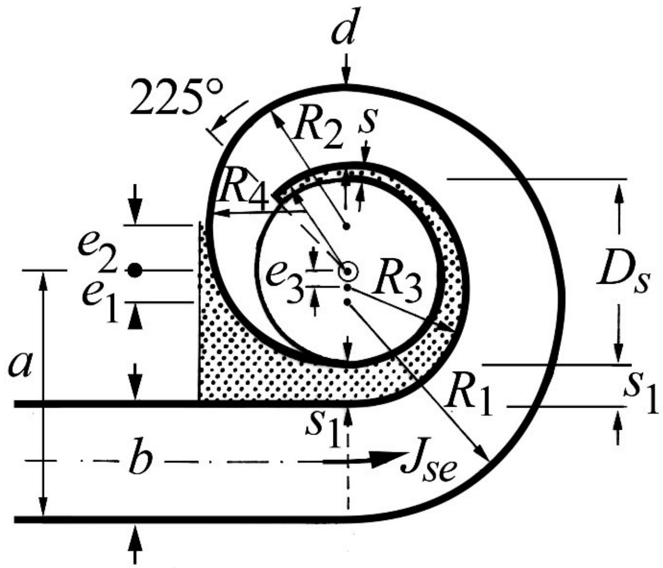
Inlet structure *super-critical* inflow (Kellenberger 1988)

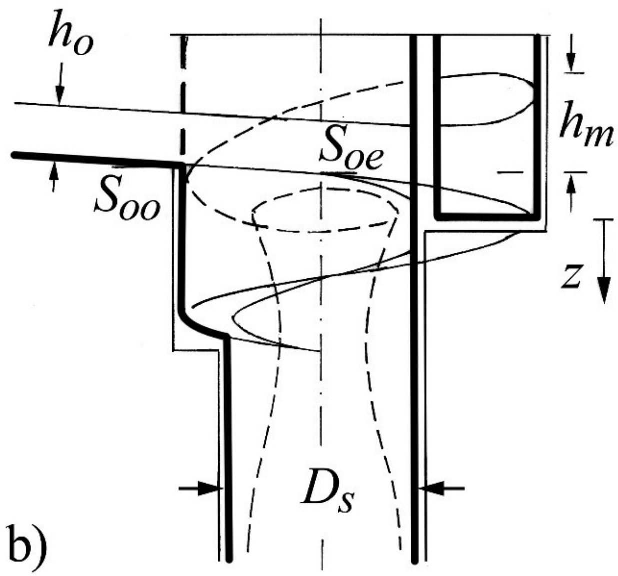
- Guidance wall along 225°
- Transverse bottom is horizontal
- $1.5 \leq F_o \leq 10$
- $S_{oe} \geq S_{oo}$ ($10\% \leq S_{oe} \leq 20\%$, max. 30%)
- Small values of b/R and d/R are favorable

Boundary conditions

- $R+s+d \leq a \leq 3R+s$
- $0.8R \leq b \leq 2R$
- $0.8R \leq d \leq 2R$

For R_1 to R_4 and e_1 to e_4 see book of Hager





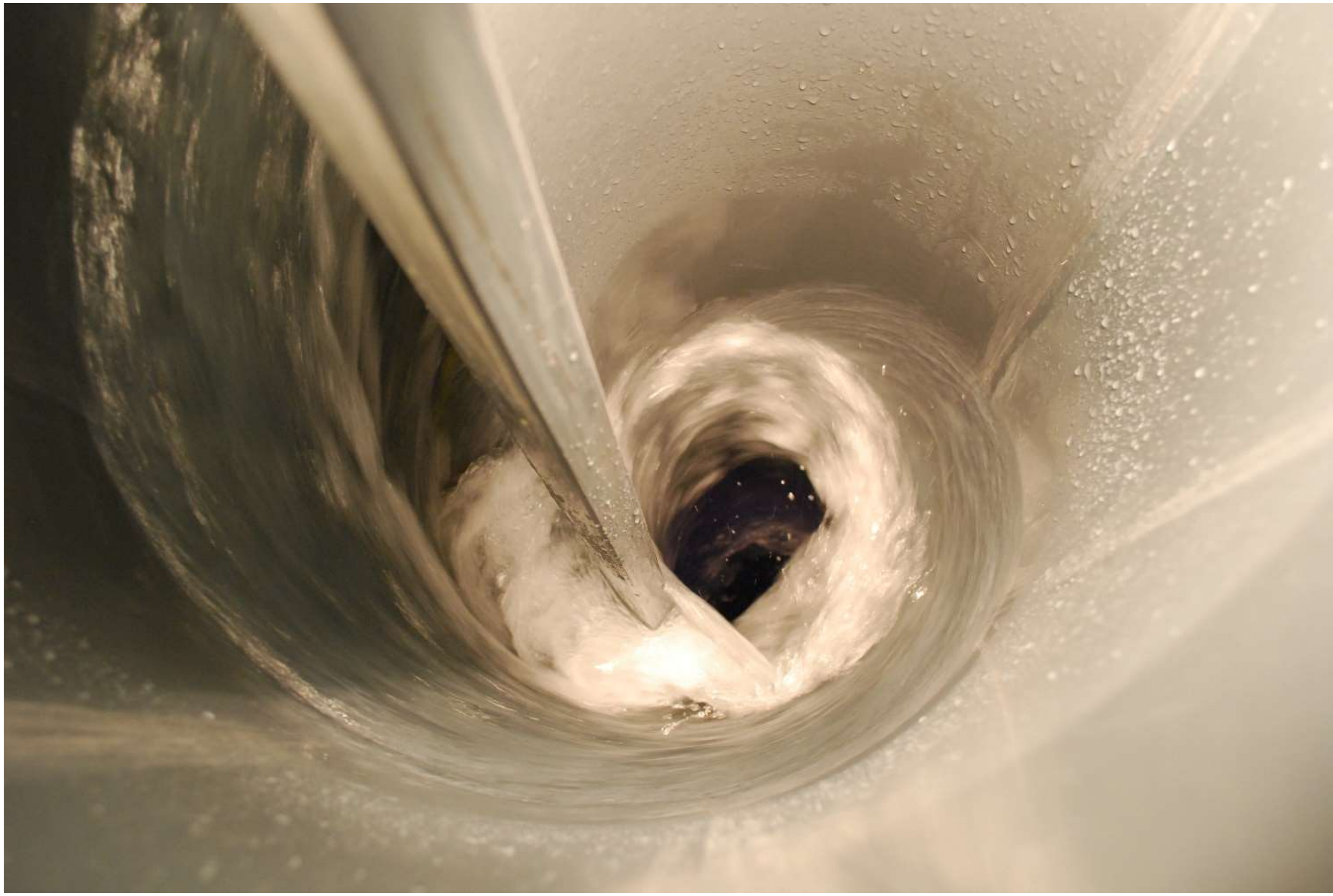
b)

7.3 Vortex drop shaft

Inlet structure *super-critical* inflow

Discharge / shaft diameter relation (with 1.25 as safety coefficient)

$$Q_M = \left(g \left(\frac{D_s}{1.25} \right)^5 \right)^{1/2}$$



7.3 Vortex drop shaft

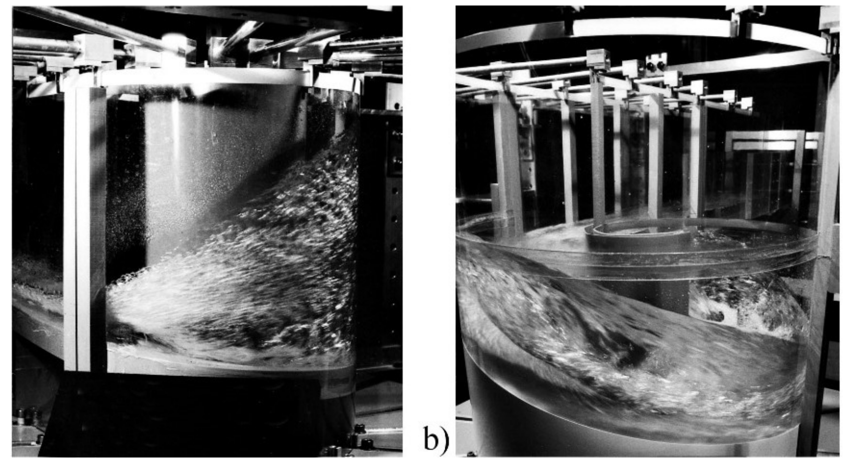
Inlet structure *super-critical* inflow

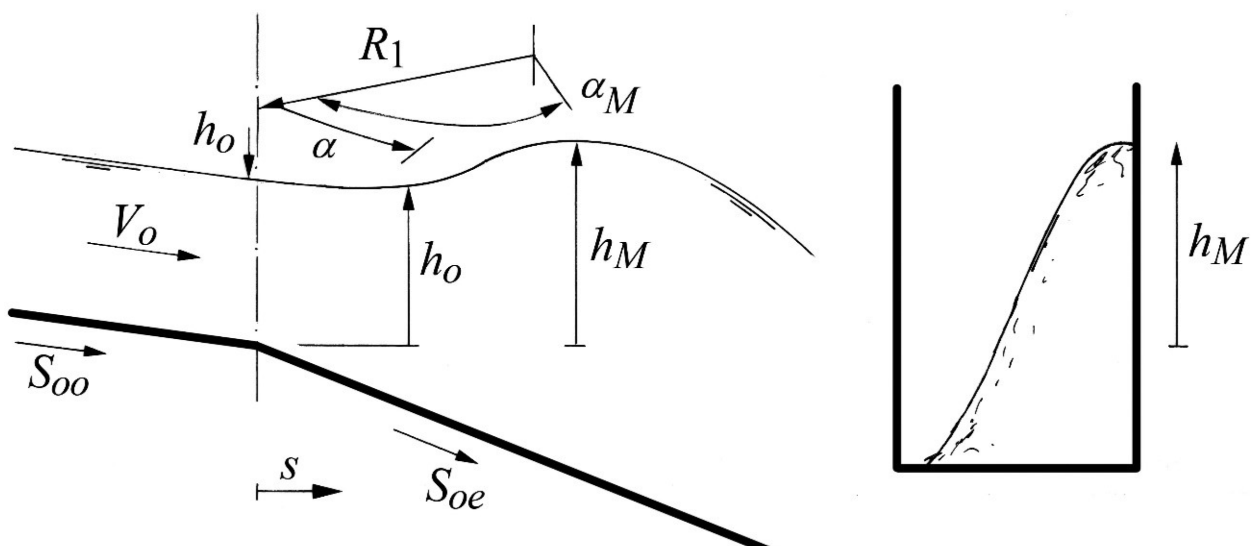
Shockwave height and location

$$\frac{h_M}{R_1} = (1.1 + 0.15\mathsf{F}_o)\left[\frac{\sqrt{2}Q}{\sqrt{gbh_o R_1^{\,3}}} - \frac{1}{2}S_{oe}\right]$$

$$\frac{\alpha_M}{\mathsf{F}_o} = 75^\circ\sqrt{\frac{h_o}{R_1}}$$

Gives height of inlet structure





a) b)

7.3 Vortex drop shaft

Vertical shaft

- Smooth surface (no guide walls!)
- Vertical axis
- Annular and rotational flow, with central air core

Upper end with drawdown curve, then "uniform flow" with equilibrium velocity

Uniform flow below z_L
(measured from inlet bottom)

$$z_L = \frac{3}{2}\frac{K^{6/5}}{g}\left(\frac{Q}{\pi D_s}\right)^{4/5}$$

Uniform end velocity

$$V = K^{3/5}\left(\frac{Q}{\pi D_s}\right)^{2/5}$$

7.3 Vortex drop shaft

Vertical shaft

Efficiency

$$\eta = \frac{\left(H_o + L_s\right) - H(z)}{H_o + L_s}$$

H_o	inflow energy head
L_s	shaft height
$H(z)$	energy head at shaft end

Gives the energy that was dissipated along the shaft (how many %), relative to the total energy

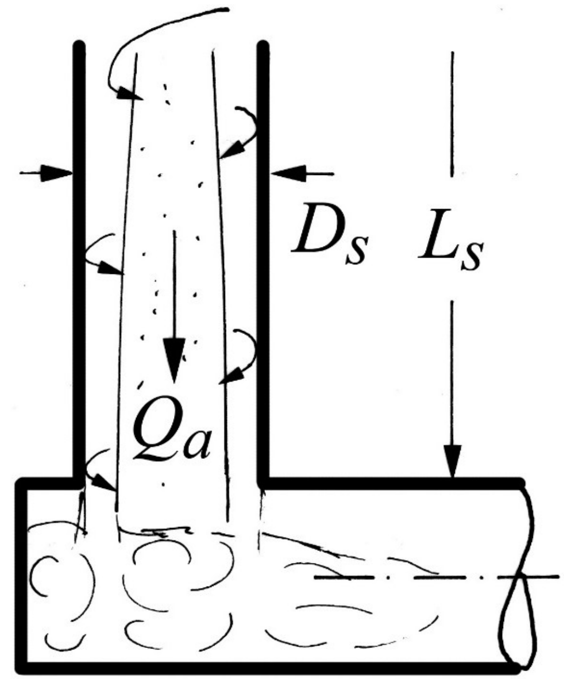
7.3 Vortex drop shaft

Vertical shaft

Air entrainment

Small discharge ⇨ shaft height relevant
High discharge ⇨ air section contraction at intake

$$\beta = \frac{Q_a}{Q} = \left(\frac{q_e}{q_s}\right)^{1/2} - 1$$



with q_e=0.018$(L_s/D_s)^{1/3}$ und q_s=$Q/(K\pi D_s^{8/3})$

Maximum air discharge is

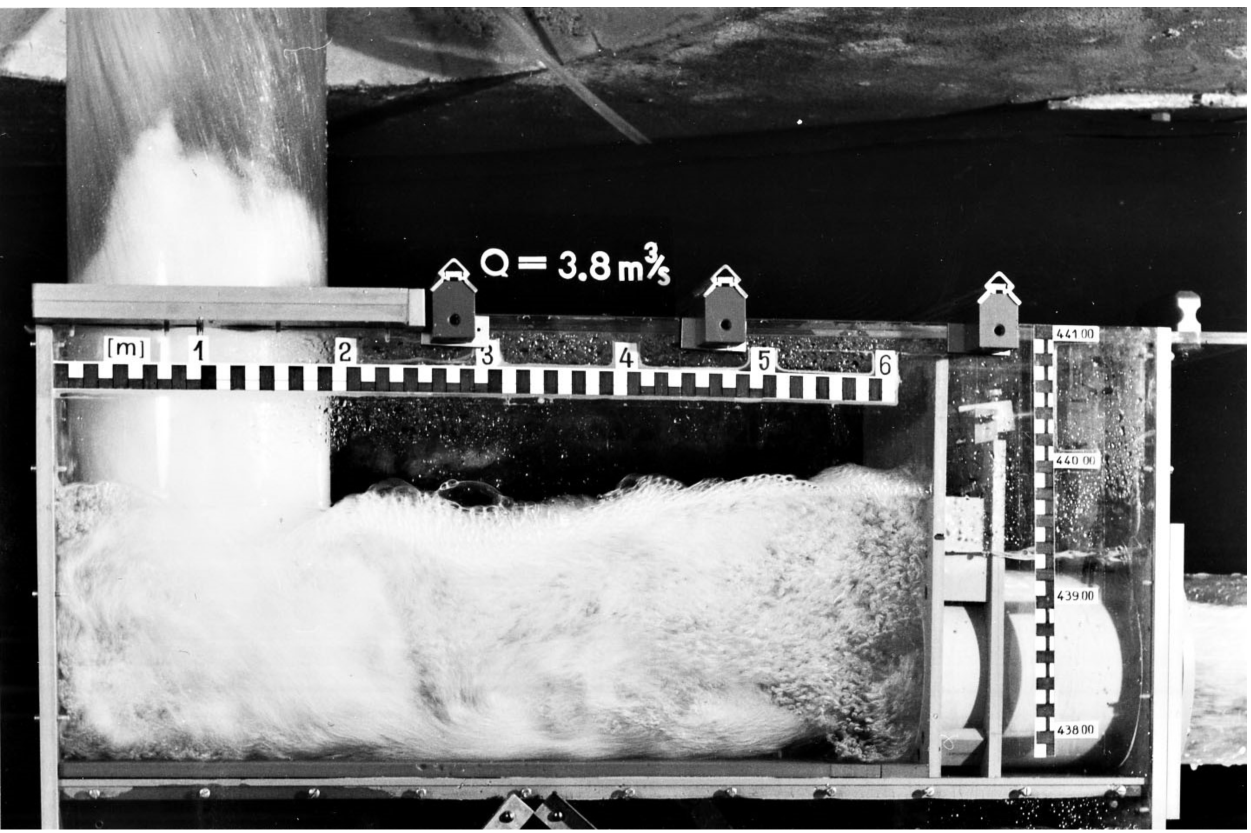
$$Q_{aM} = \frac{1}{4} q_e K \pi D^{8/3}$$

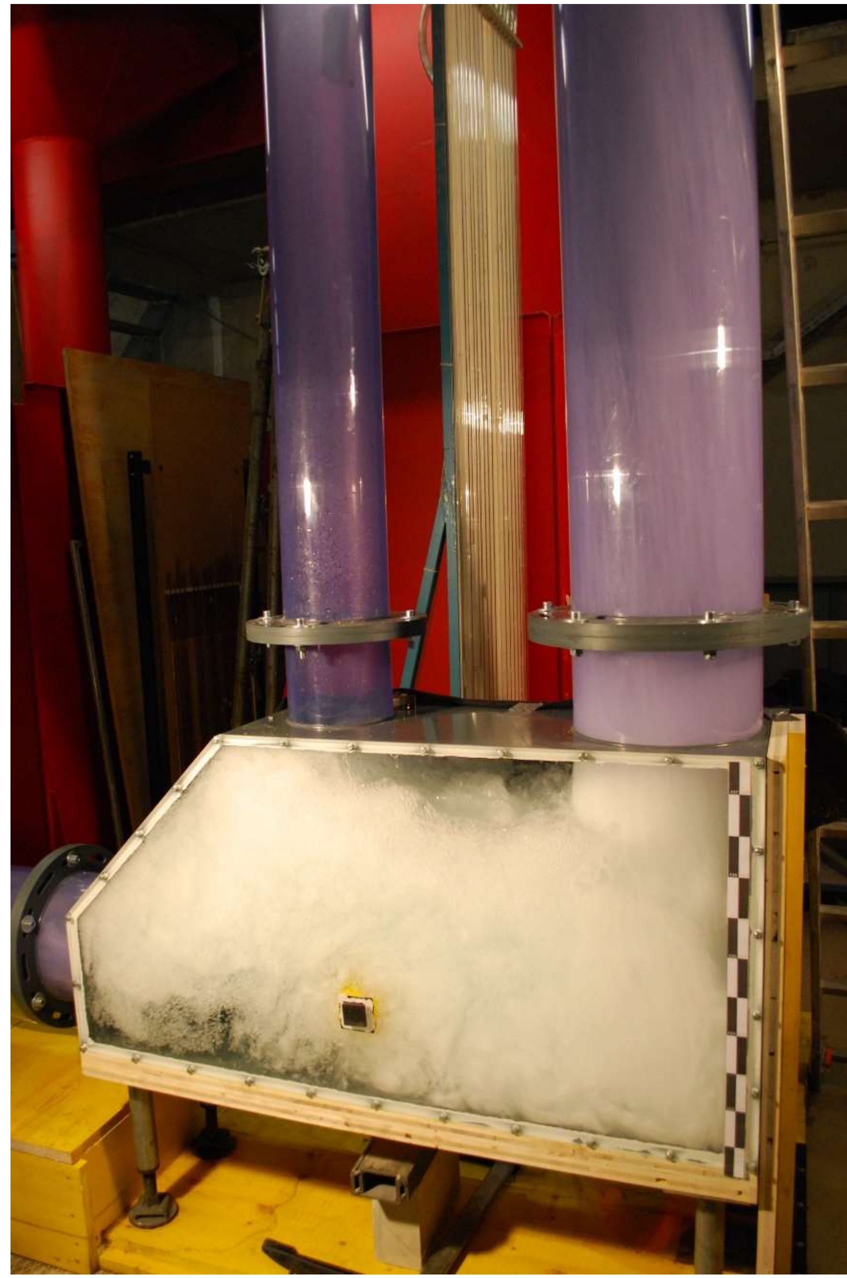
Where is this air after being entrained through the shaft?

7.3 Vortex drop shaft

Dissipation chamber

- Dissipates residual energy
- De-aerates the flow
- Transfers vertical to horizontal flow





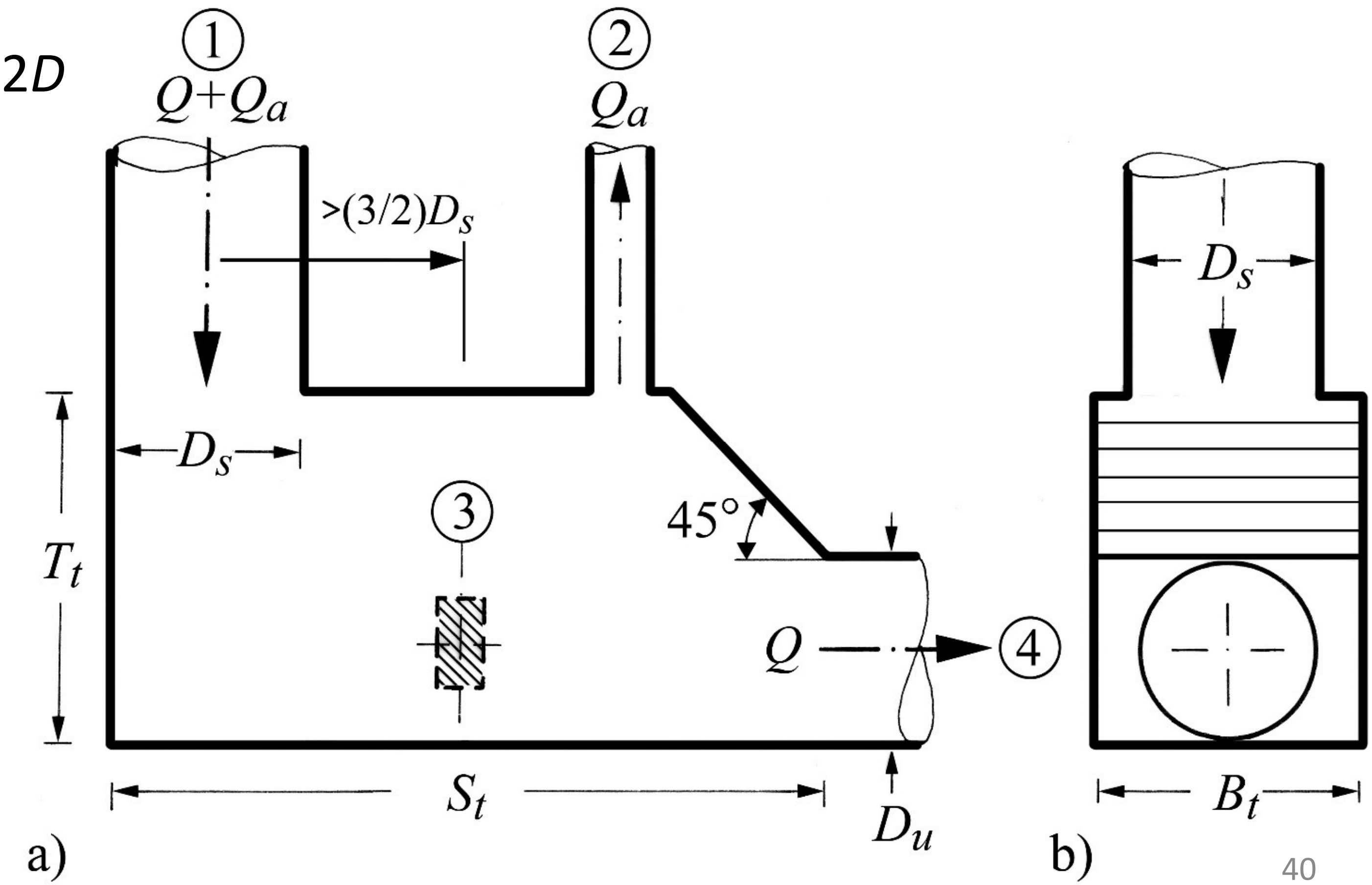
7.3 Vortex drop shaft

Dissipation chamber

- Dissipation chamber should never choke
- Do not extend the shaft into the chamber

D is larger value of D_s and D_u

$S_t \cong 4D$, $B_t \cong 1.2D$ und $T_t \cong 2D$



7.3 Vortex drop shaft

Dissipation chamber

Wiggen drop shaft in Rorschach (CH) during a minor rain event. (Weiss, et al. NOVATECH 2010)

7.3 Vortex drop shaft

Dissipation chamber

Aeration

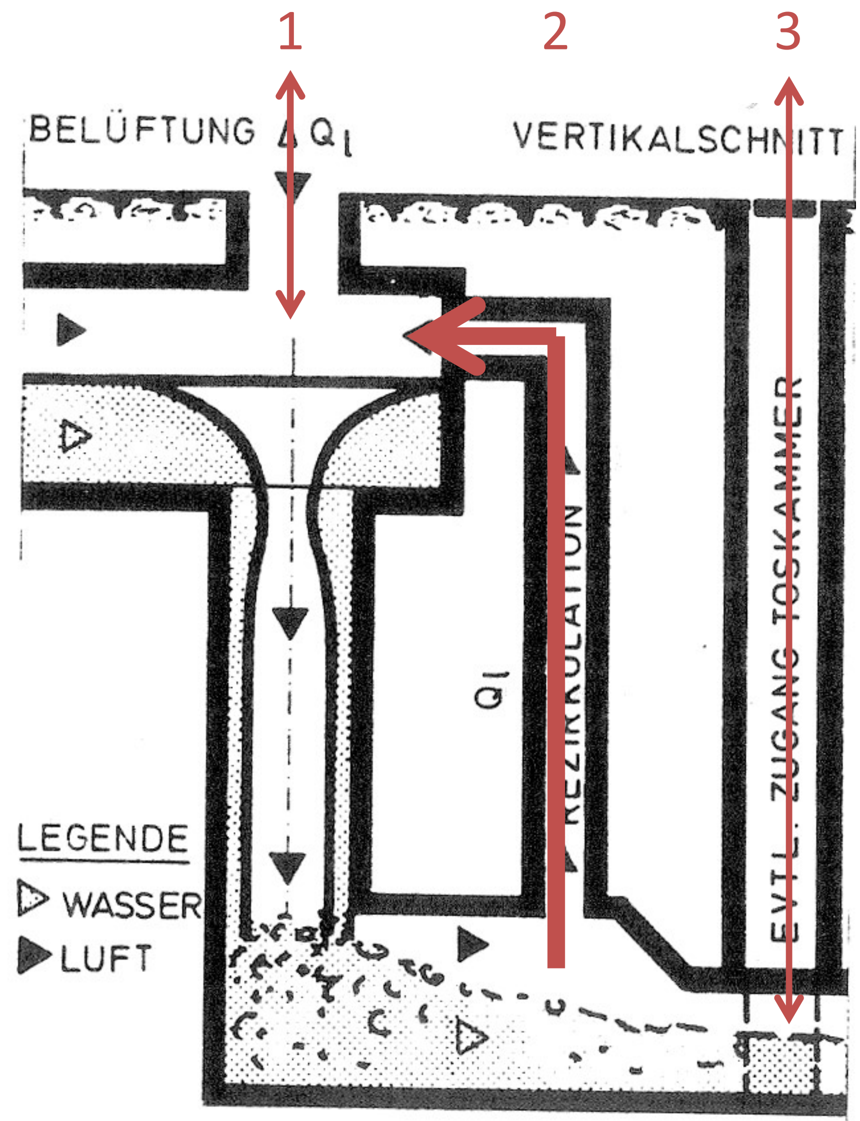
The system fails (and is damaged) without sufficient aeration. Short-circuit mode to avoid odor and noise.

Three aerations:

1. Between intake to free surface (in manhole, provide pressure equilibrium, compensate air deficits)
2. Large re-circulation pipe from chamber to intake (dominant air flow)
3. Small conduit aeration (d/s of chamber) to allow free surface flow

Re-circulation pipe

V_{aM} between 30 and 50 m/s

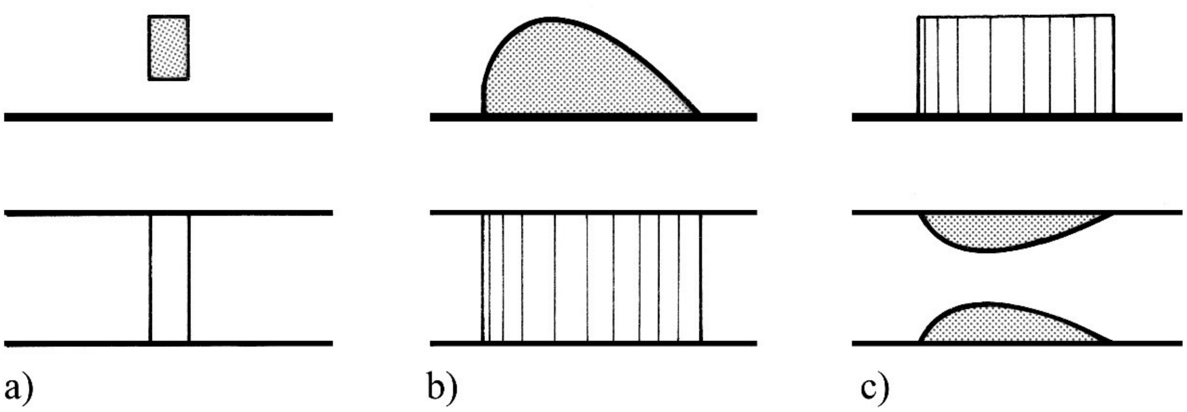


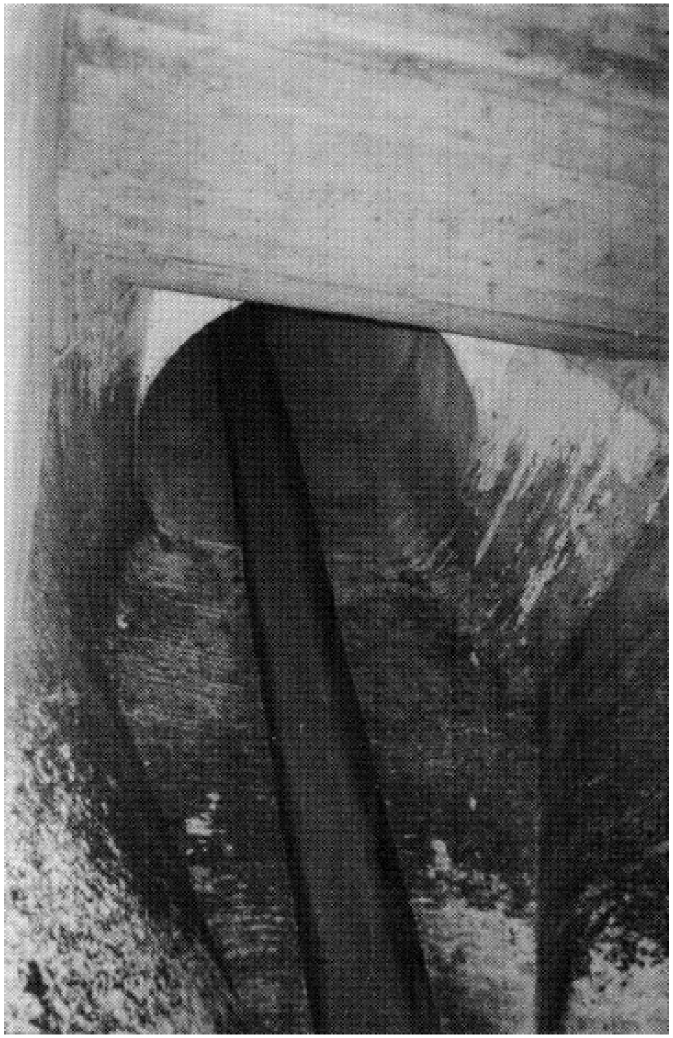
7.3 Vortex drop shaft

Dissipation chamber

- Small discharges: weak water cushion at impact.
- Insets generated higher flow depths

For chamber as presented, these insets are usually not required. If anyway required: use Venturi type to avoid blocking and depositions



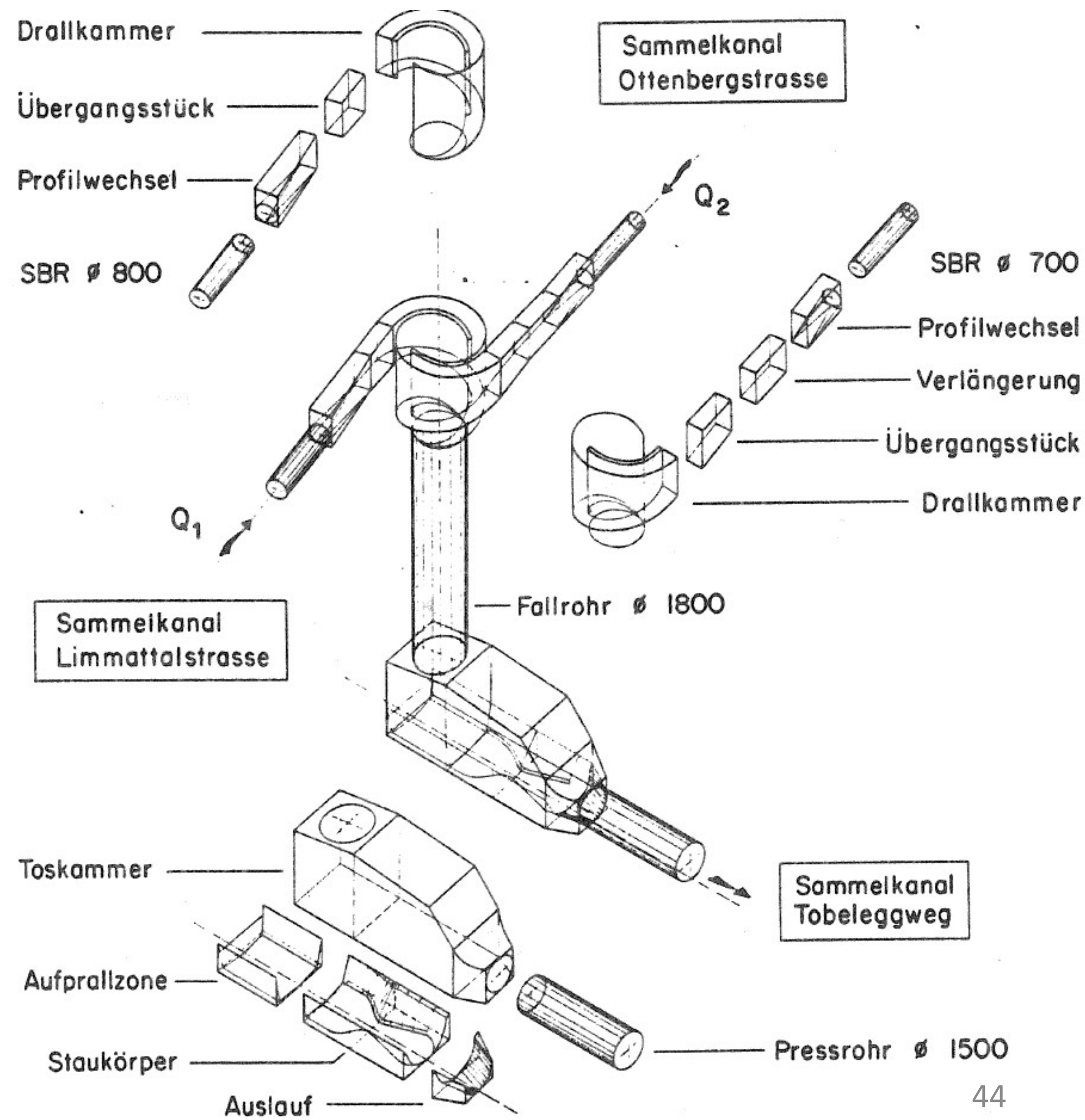


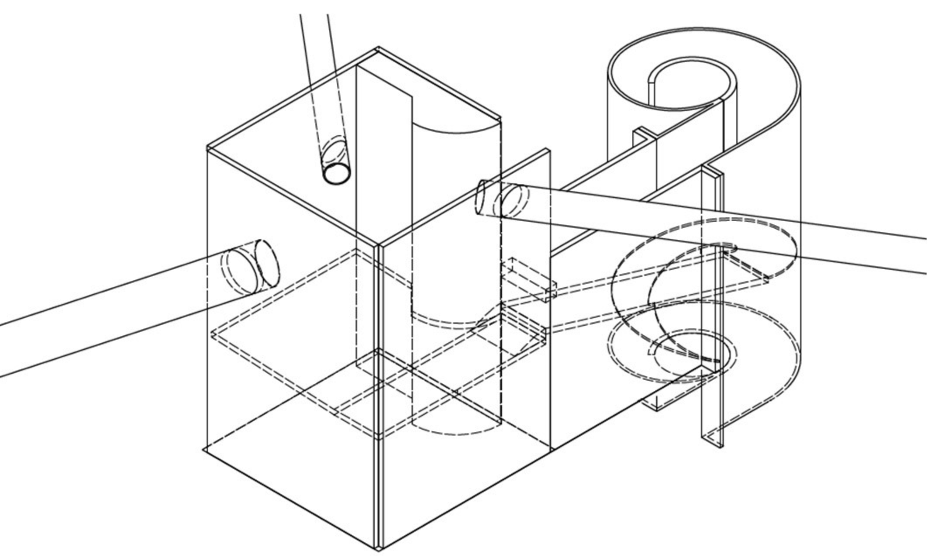
7.3 Vortex drop shaft

Vortex drop shaft combined with junction at intake (VSA)

Model tests necessary!

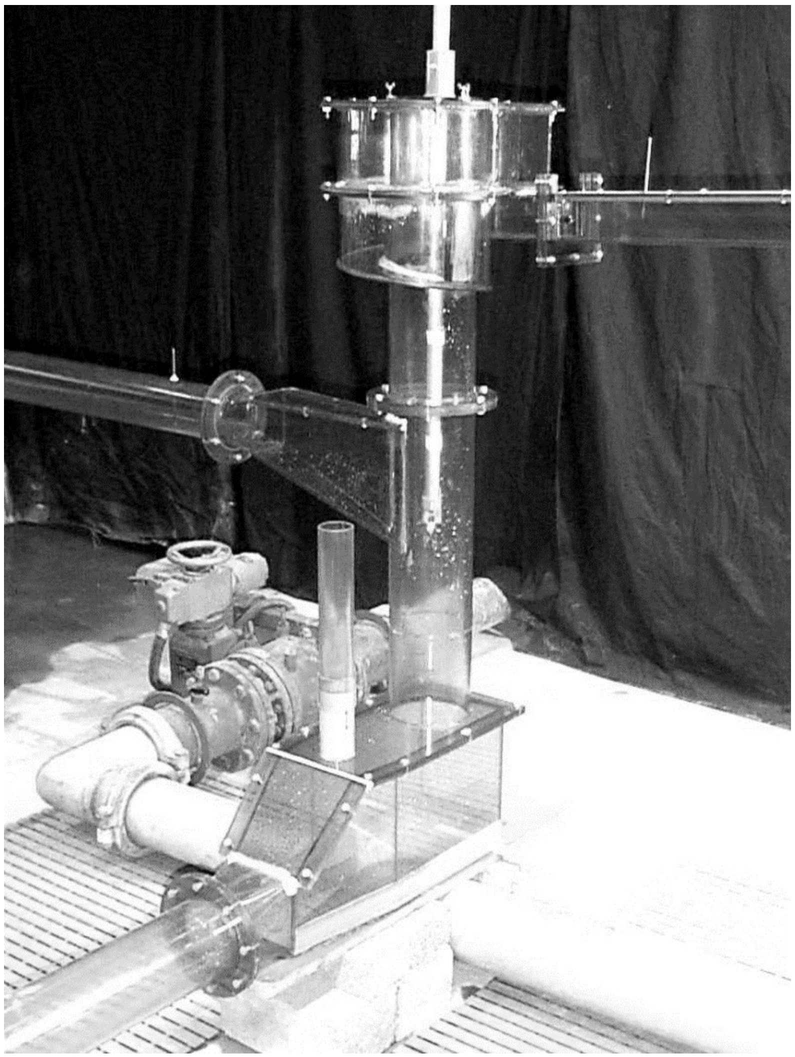
Right: VSA
Below: LCH





7.3 Vortex drop shaft

Vortex drop shaft
combined with junction
at intake



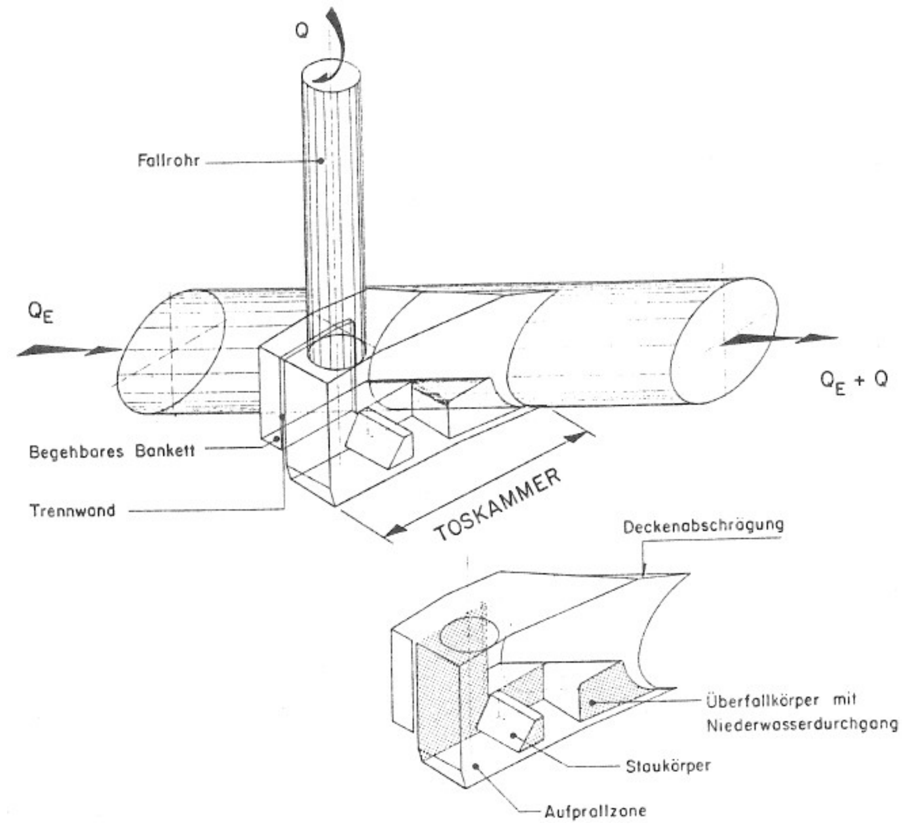
Left: Ville de Friboug, LCH
Right: Stadt Bern, VAW

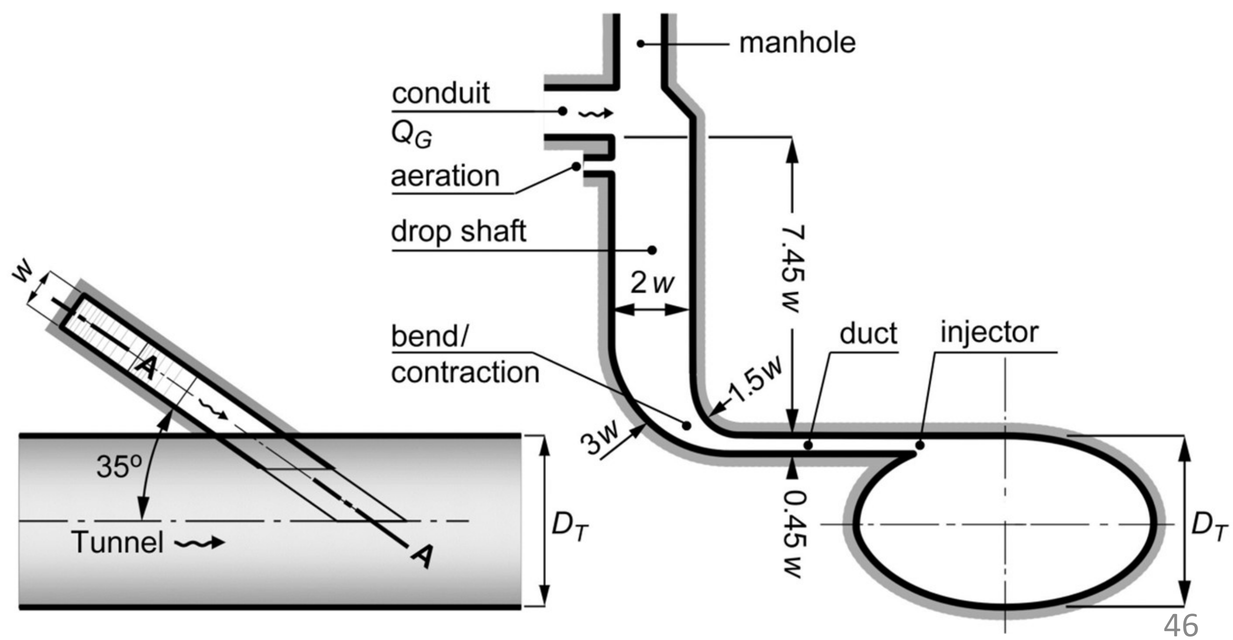
7.3 Vortex drop shaft

Vortex drop shaft combined with junction at dissipation chamber

Top: VSA
Bottom: VAW

Model tests necessary!





7.3 Vortex drop shaft

Design procedure

1. Check inflow conditions, assume uniform flow with h_N and F_N, define intake structure
2. Choose shaft Diameter (for sub- or super-critical flow)
3. Define constructional details of intake, as s, c, ΔR. Check boundary conditions
4. For sub-critical design: ensure that $h_o<h_N$. For super-critical design, define shock wave height h_m
5. (Verify if uniform conditions in shaft occurs)
6. Define size of dissipation chamber
7. Compute air demand and design aeration systems

7.3 Vortex drop shaft

Questions to ask (VSA 483)

- Spilling $Q_k = nQ_m$ separately via bypass (n=1 to 3. Reason: high [abrasive] load at dry-weather discharge during 90% of operation time)
- All solids via shaft?
- Vibration of base plate in dissipation chamber
- Abrasion and cavitation on base plate
- Joints at base plate (= weakest elements)
- Aeration with recirculation
- Stable flow features
- Guarantee free surface flow with small partial filling ratio in downstream conduit
- Construction process
- Accessibility and minimum dimensions for maintenance
- Be careful: the water cushion in the dissipation chamber exists only for (rare) high discharges. For usual (small) discharges, the base plate is not protected by it.

7.3 Vortex drop shaft (I)

EXAMPLE: Design of vortex drop shaft

Inflow channel: b=0.8 m, S_{oo}=5%, K=80 m$^{1/3}$/s, Q_M=3 m^3/s, L=15 m

7.3 Vortex drop shaft (II)

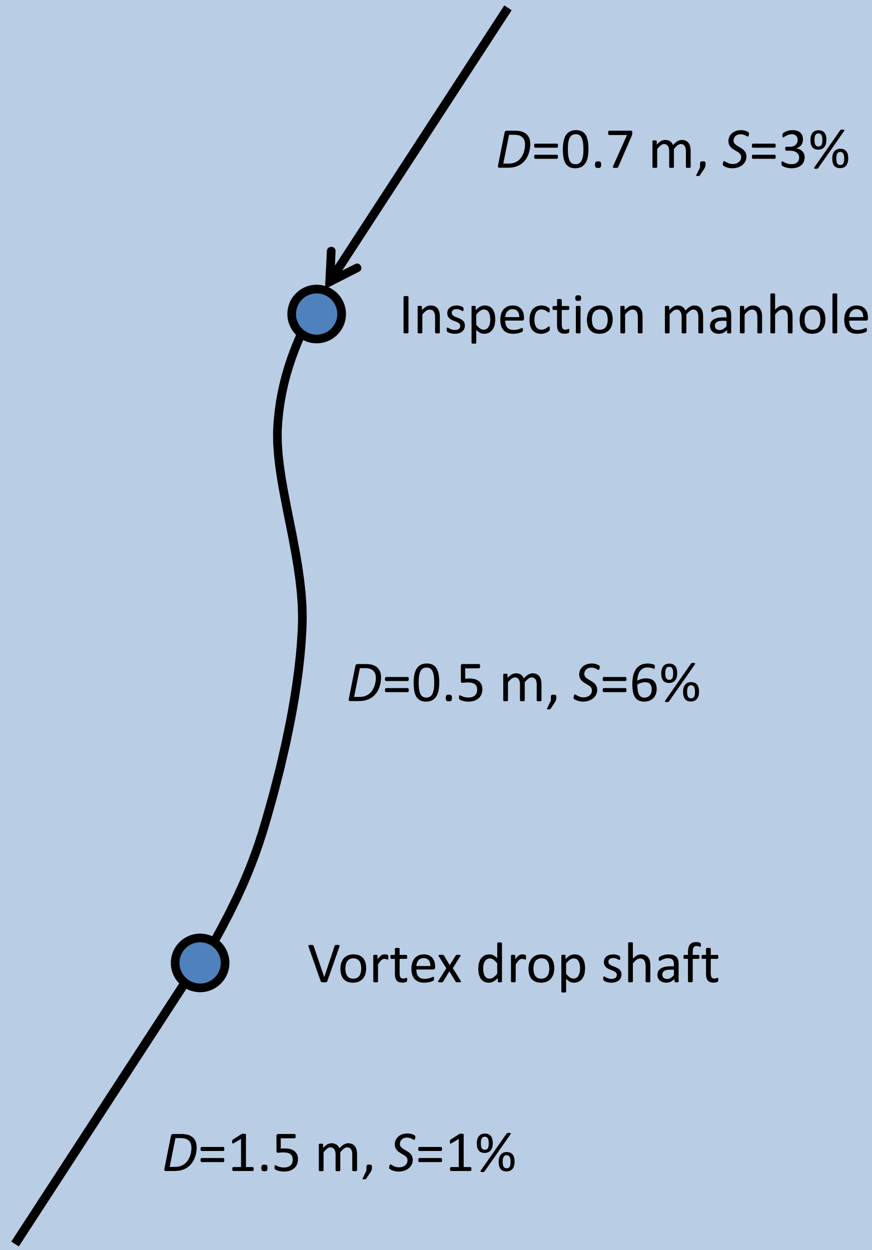
Example

Does it work?

Vortex drop shaft

$H \approx 20$ m

$F_o \approx 10$



7.4 Baffle drop shaft

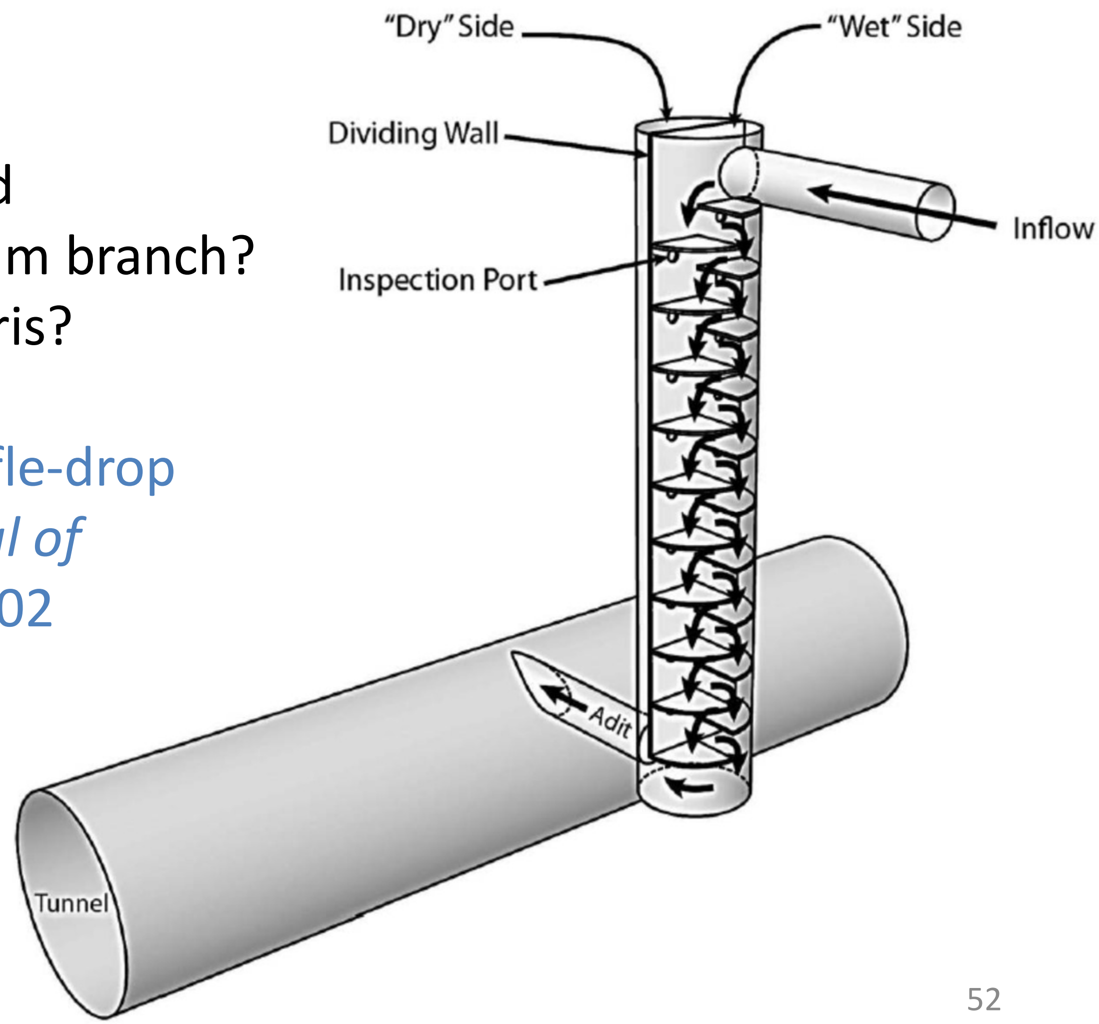
7.4 Baffle drop shaft

Baffle drop shaft

- For drop heights H<70 m and Q<13 m^3/s
- Connection to various collectors at different heights and orientations

- Powerful aeration system required
- Noise, odor, choking of downstream branch?
- Abrasion and blocking due to debris?

Odgaard, Lyons and Craig (2013). Baffle-drop structure design relationships. *Journal of Hydraulic Engineering* 139(9), 995-1002

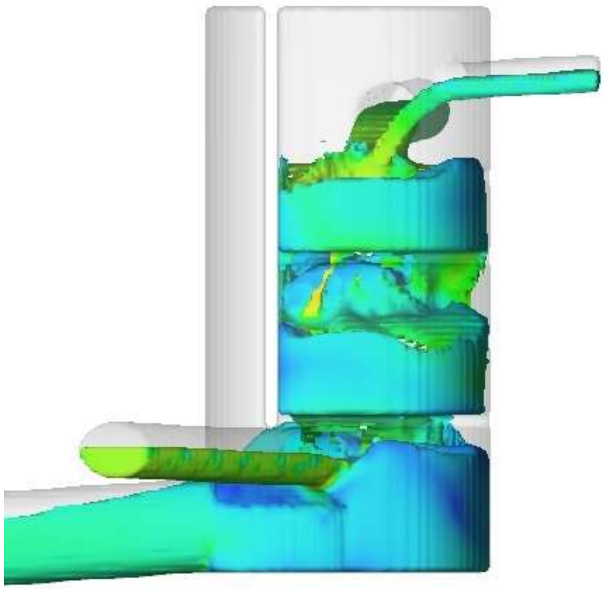


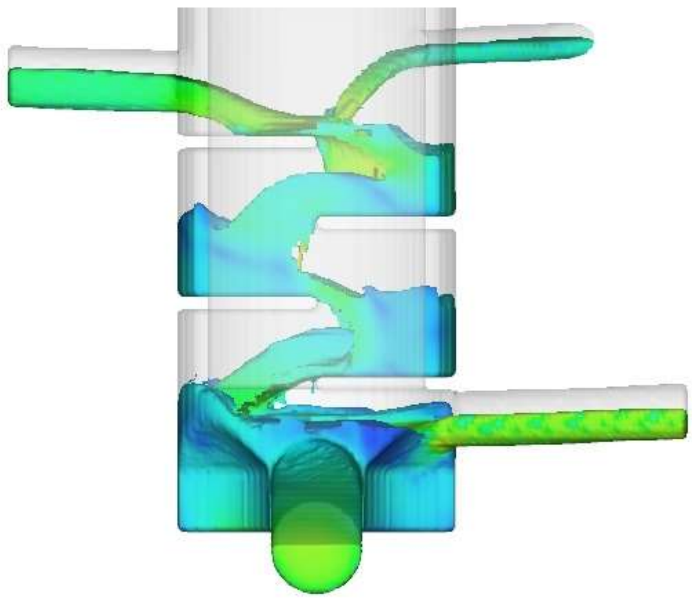
7.4 Baffle drop shaft

Baffle drop shaft

- Etouffement des conduites connectées ?
- Grand regard… travaux d'excavation (pousse-tube ou micro-tunnelier) ?
- Raccordement à la galerie existante possible ?
- Etouffement de la galerie de sortie (aération!) ?
- Validation au moyen de simulations numériques ou de tests sur modèles réduits actuellement encore nécessaire…

(HEIA-FR)

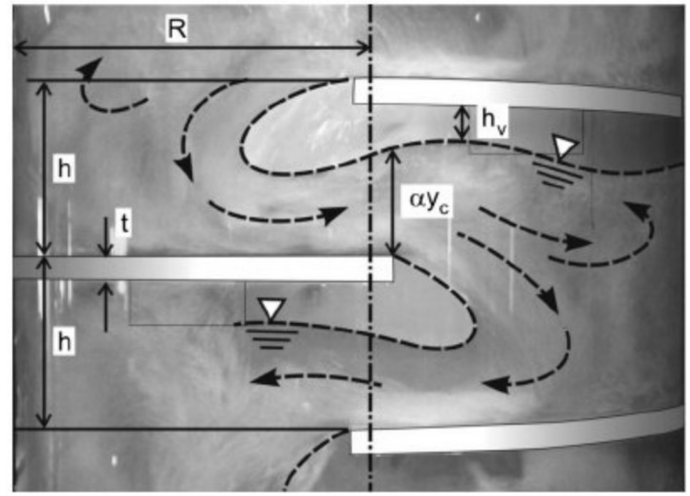




7.4 Baffle drop shaft

Baffle drop shaft

Desing following Odgaard, Lyons and Craig (2013). *Baffle-drop structure design relationships*. JHE 139(9), 995-1002

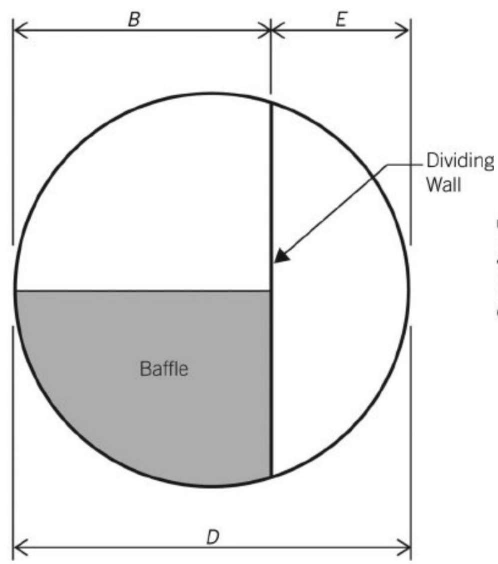


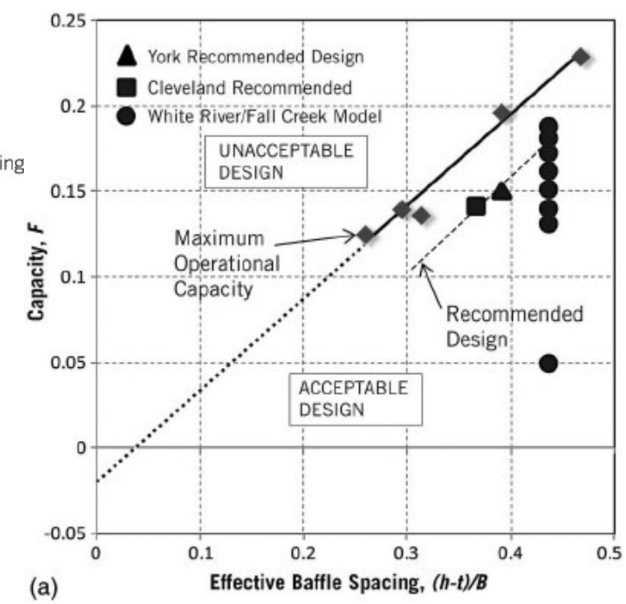
Shaft diameter (approximation)

$$D_S = {Q_M}^{2/5} \frac{6}{g^{1/5}}$$

Baffle spacing (graph at right) gives capacity number F (➲ Q_C)

$$F = \left(\frac{{Q_C}^2}{B^5 g}\right)^{1/3}$$





(a)

7.4 Baffle drop shaft

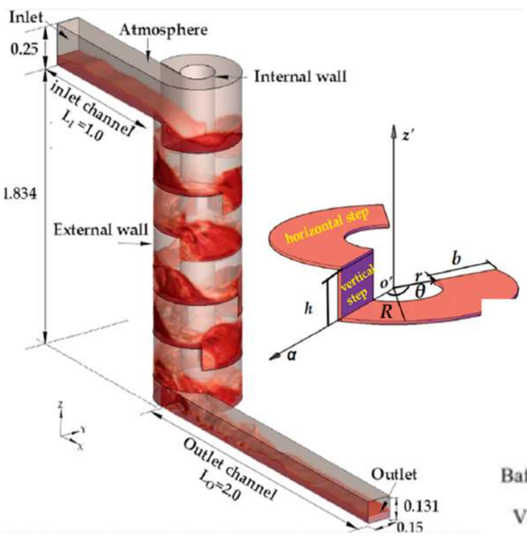
Baffle drop shaft

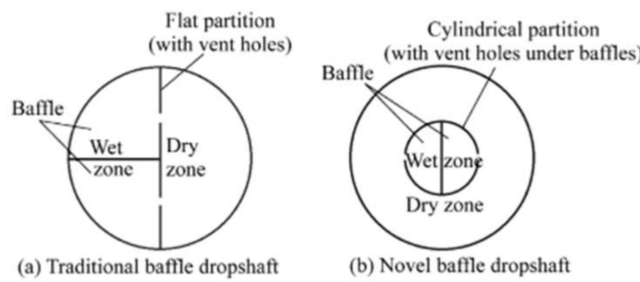
Design to be validated in numerical or physical tests.
Ruisseau de la Broye, Renens (physical modelling LCH, EPFL)

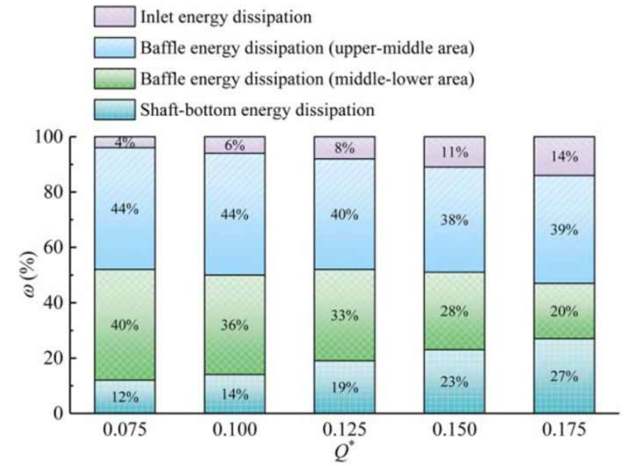
7.4 Baffle drop shaft

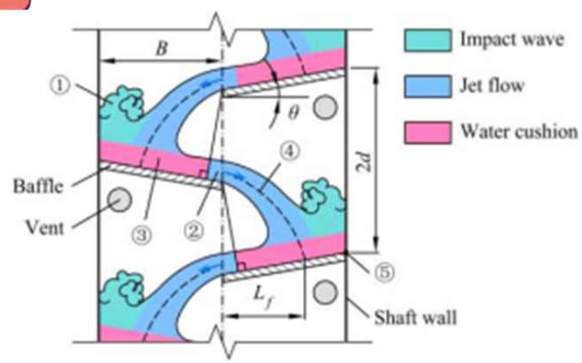
Baffle drop shaft

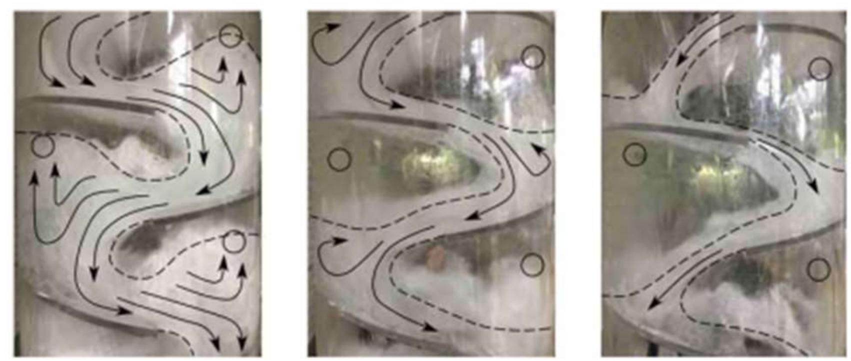
Current literature…











- Qi, Wang and Zhang (2019). Three-Dimensional Turbulence Numerical Simulation of Flow in a Stepped Dropshaft. Water 11(1), 30
- Wang, Zhang, Fu, Xu, Xu and Zhou (2020). Influences of flow rate and baffle spacing on hydraulic characteristics of a novel baffle dropshaft. Water Science and Engineering 13(3), 233-242
- Yang and Yang (2020). Experimental investigation of hydraulic characteristics and energy dissipation in a baffle-drop shaft. Water Sci Technol 82(8), 1603-1613
- Yang and Yang (2021). Numerical investigation of the turbulence characteristics and energy dissipation mechanism of baffle drop shafts. Water Sci Technol 83(9), 2259-2270.

7.5 Pro memoria

7.5 Pro memoria

Drop manhole

- For drop heights up to 10 m and Q<2.5 m^3/s
- Dry-weather bypass and storm water drop chamber
- Noise, odor, choking of lower branch
- Use SIA design
- Design considering Q_m and Q_M (impact wall crest height), and outlet-height h_o
- Provide sufficient aeration
- Respect minimum dimensions

Questions?

7.5 Pro memoria

Vortex drop shaft

- Drop height from 10 (below is not economic) to some 100 m (or more)
- Consists of intake chamber, vertical shaft and dissipation chamber
- Separates (annular) water and (core) air flow
- Relevant energy dissipation by wall friction in shaft
- Two intake concepts (F_o<0.7 or F_o>1.5)
- Vertical shaft with smooth surface, absolute circular
- Maximum air entrainment equal to water discharge
- Provide sufficient aeration
- Use standard dimensions for dissipation chamber
- If any difference to standard design necessary: assign laboratory with model tests

Questions?