8. Junction manhole

Urban Hydraulic Systems
Prof. Dr. Michael Pfister

8. Junction manhole

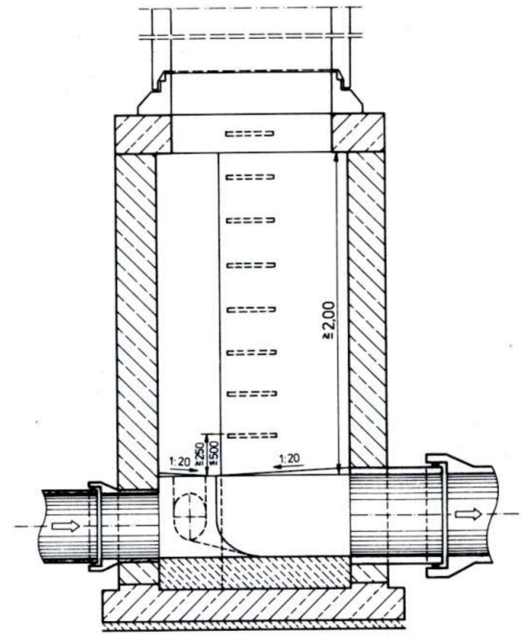
Goals of this chapter

Combining conduit junctions are a frequent standard or special manholes

- ➢ Many concepts exist, which one is adequate?
- ➢ How are they designed?
- ➢ What is the flow characteristics?

Two types following the inflow characteristics:

- Sub-critical flow design
- Super-critical flow design



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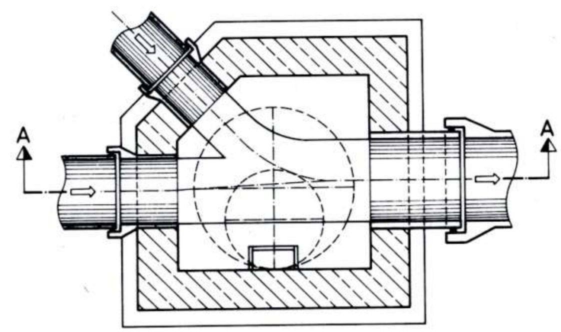

Grundriß

8. Junction manhole

Context

8.1 Introduction
8.2 Sub-critical approach flow
8.3 Super-critical approach flow
8.4 Pro memoria

Literature

W.H. Hager (1999). *Wastewater Hydraulics*, Springer, Berlin
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Séminaire VSA/EPFL (2013). *Hydraulique des canalisations*
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8.1 Introduction

8.1 Introduction

Goals of junctions

- Combine two flows with a minimum energy loss (for sub-critical approach flow in “flat” topography)
- Combine two flows with a maximum discharge capacity (for super-critical approach flow in “steep” topography)
- Avoid phenomena limiting the capacity (for example shockwaves causing choking)

➢ For small conduit diameter and sub-critical approach flow ⇨ standard manhole without design

➢ For large D>0.8 m or super-critical approach flow ⇨ special manhole

8.1 Introduction

Sub-critical approach flow conditions

- Basic hydraulics of junctions often refers to pressurized flow
- Similar flow features for open channel and pressurized flow for $\mathbf{F_u<0.7}$
- Friction losses are relevant for the hydraulic features, flow depths are computed for design purposes
- Friction losses are compensated by the bottom slope (in manhole only)

Super-critical approach flow conditions

- Merging two super-critical flows is almost impossible…
- Shock waves at bend and where the flow merges occur, resulting in flow choking (swell) at the end of the junction
- The discharge capacity is the limiting issue considered for design purposes
- Often big conduit diameters necessary, together with extension elements

8.1 Introduction

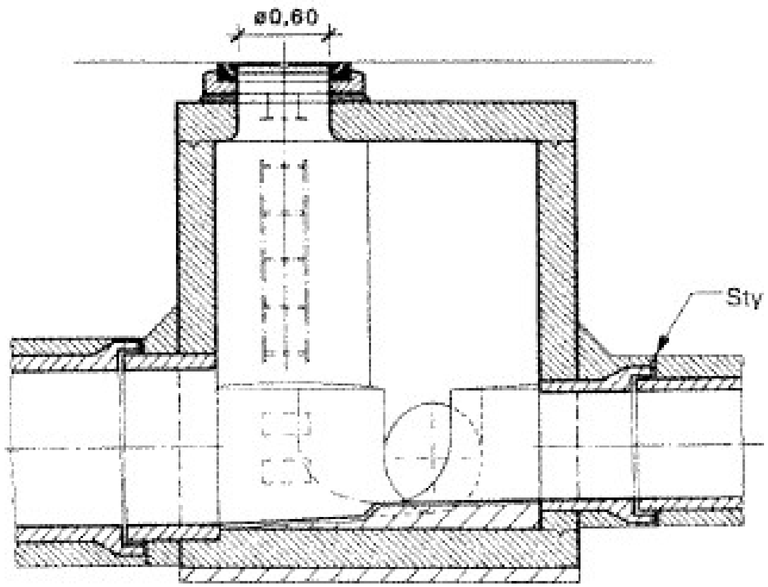
Left: Sub-critical flow conditions
Right: Super-critical flow conditions

Same geometry, same partial filling ratio

8.1 Introduction

Sub-critical flow conditions: standard design (Bernoulli)

(SIA, ATV)



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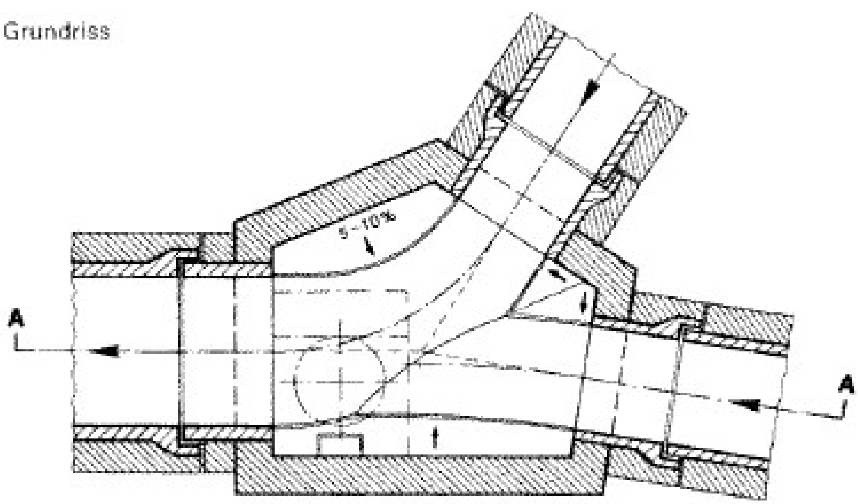

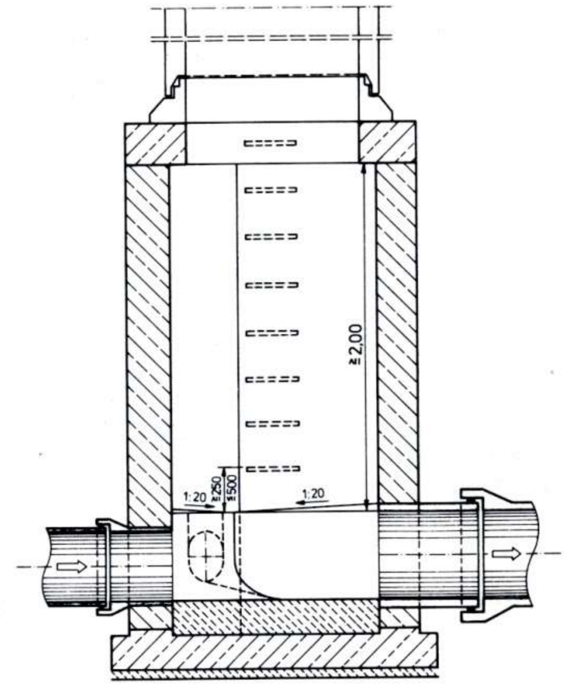

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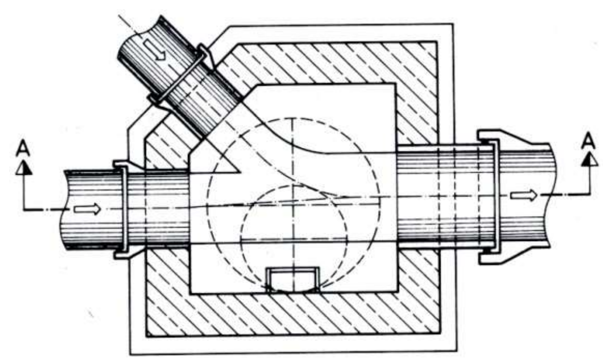
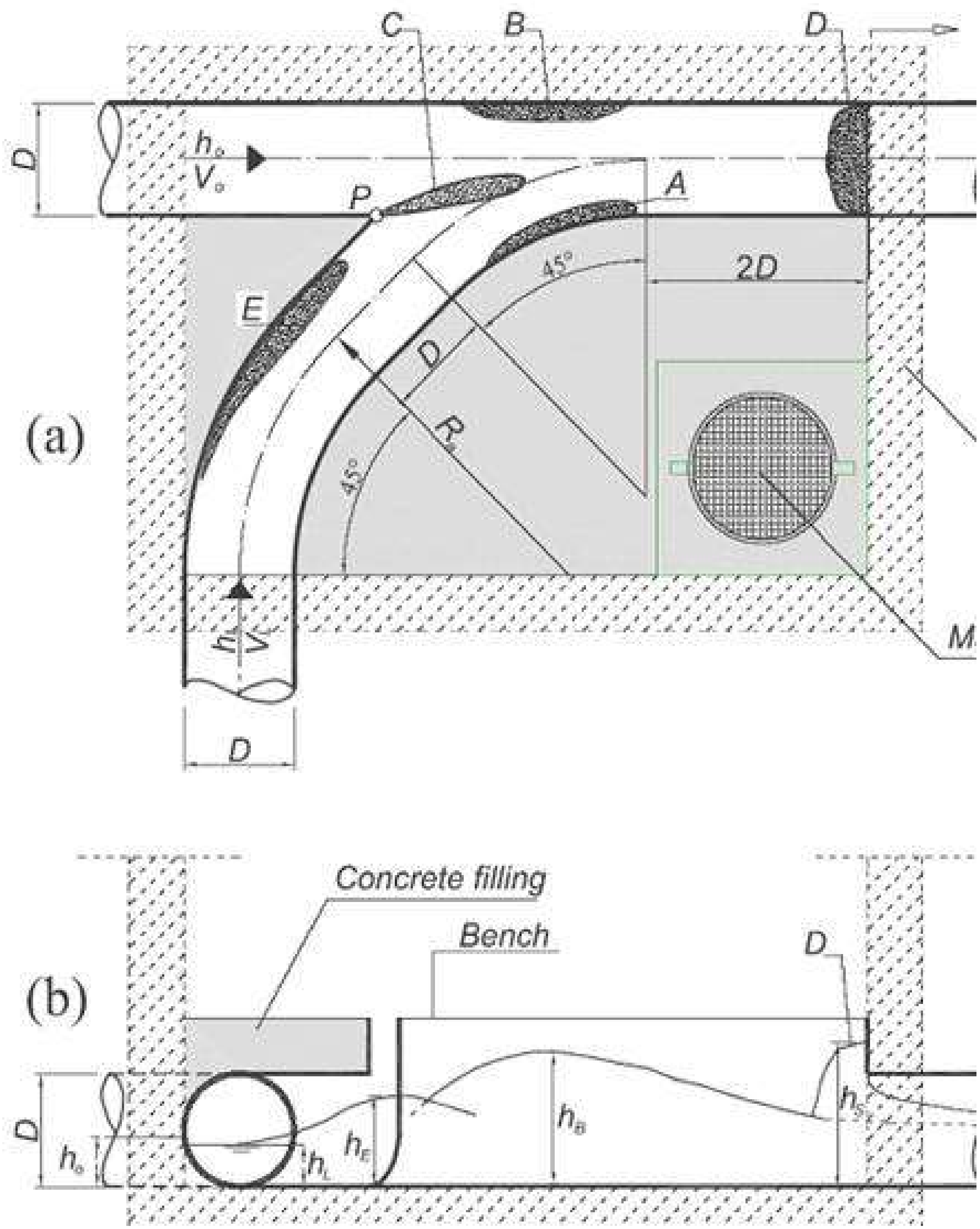


Grundriß

8.1 Introduction

Super-critical flow conditions:
Hager & Gisonni design



8.2 Sub-critical approach flow

8.2 Sub-critical approach flow

Sub-critical flow conditions … hydraulic computation against flow direction

Bases:

- Manhole geometry is known (simplified ? Small changes are neglected)
- Downstream uniform flow (*U*) conditions Q_U, U_U, h_U are known (computation direction against stream for sub-critical conditions)
- Specify Q_O and Q_Z in the two upstream branches (*O* as main branch, and *L* as lateral branch)

Bernoulli (with local and streamwise losses):

- Downstream *U* to main branch *O* $H_o+\Delta z=H_u+\xi_o[V_U^2/2g]+\Delta h_f$
- Downstream *U* to lateral branch *L* $H_z+\Delta z=H_u+\xi_z[V_U^2/2g]+\Delta h_f$

With:

- *H* as specific energy head (relative to the bottom)
- Δz as bottom elevation difference
- *V* as flow velocity
- h_f as friction losses head

8.2 Sub-critical approach flow

Assumption (in the Bernoulli equation):

- Δz und Δh_f are small and compensate each other → remove
- For F<1 is $V^2/2g<h$ → relate to A_U: $V_O=Q_O/A_U$ und $V_Z=Q_Z/A_U$

Flow depths (at the entrance to the junction) of the two upstream branches result as

- Main branch $$h_o - h_u = \frac{(1+\xi_o)Q_u^{\ 2} - Q_o^{\ 2}}{2gA_u^{\ 2}}$$

- Lateral branch $$h_z - h_u = \frac{(1+\xi_z)Q_u^{\ 2} - Q_z^{\ 2}}{2gA_u^{\ 2}}$$

Use h_o and h_z as start value to derive the backwater curve (computation in the upstream direction) towards uniform flow in *O* and *L*

8.2 Sub-critical approach flow

Junction with various geometrical parameters exist…

- The local loss coefficients ξ_o and ξ_z are required ⇨ literature!
- Partially rather pronounced local energy losses, not to be ignored…
- Loss coefficients are derived for pressurized flow, they may be adapted to free surface flows if F_U<0.7

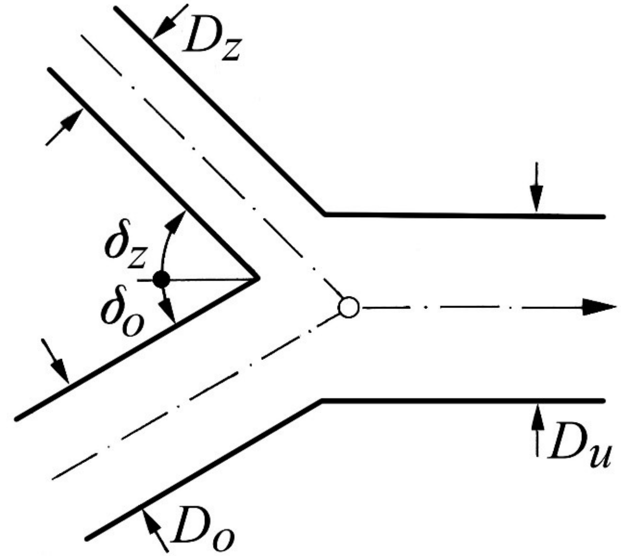
Again: reference velocity is V_U as the others could be zero

$$\xi_o = \frac{H_O - H_U}{V_U^{\ 2} / 2g} \qquad \xi_z = \frac{H_Z - H_U}{V_U^{\ 2} / 2g}$$

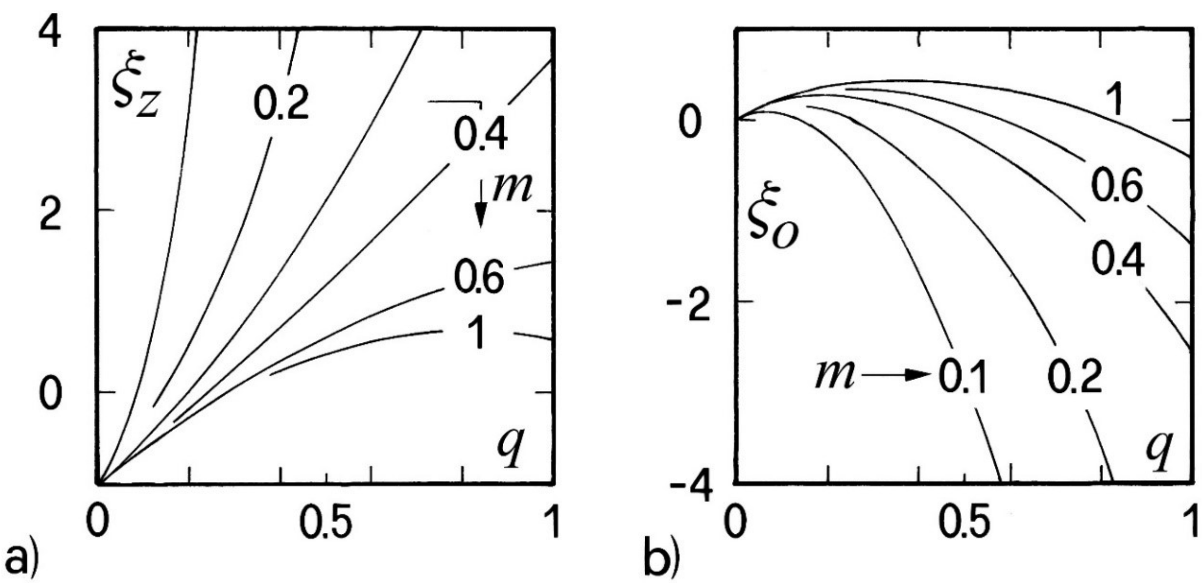
8.2 Sub-critical approach flow

Local loss coefficients (I)

$$m = \frac{A_Z}{A_U} \quad n = \frac{A_O}{A_U} \quad q = q_Z = \frac{Q_Z}{Q_U}$$



- Main branch straight with δ_O=0° and n=1
- Lateral branch with δ_Z=45°
- Sharp edges

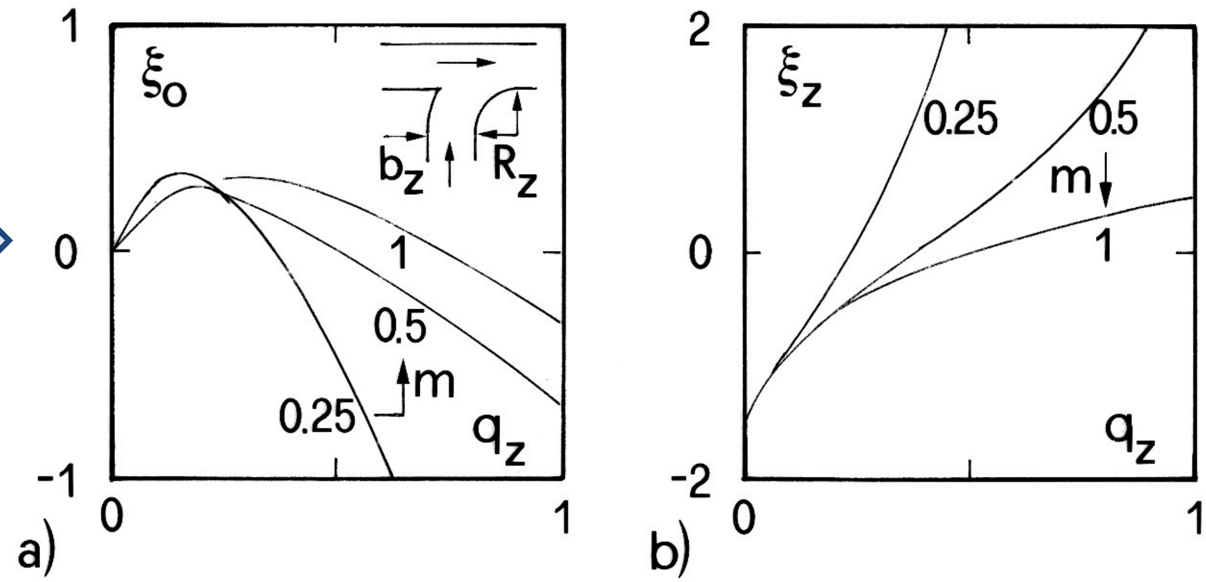


- Negative loss coefficients for main branch!
- Main flow is aspired by lateral flow
- “energy gain” for main branch
- Nevertheless, *Head loss*>0 (Junction = Energy loss)

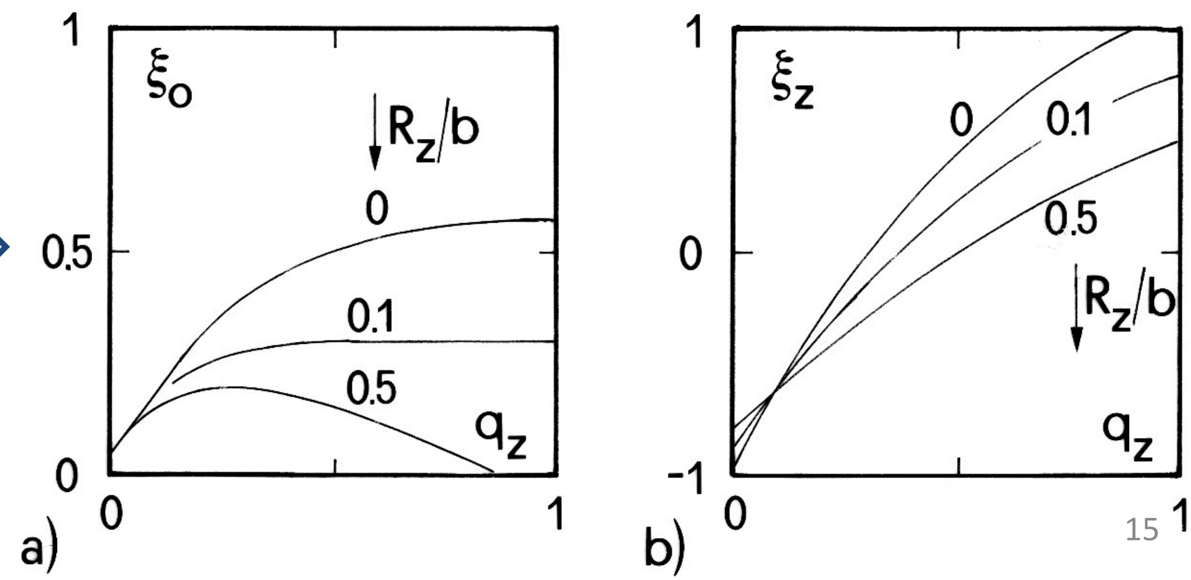
8.2 Sub-critical approach flow

Local loss coefficients (II): Rounded edges at lateral branch reduce losses

- Main branch straight with δ_O=0° and n=1
- Lateral branch with δ_Z=90°
- Rounded edges
- R_Z=b_Z



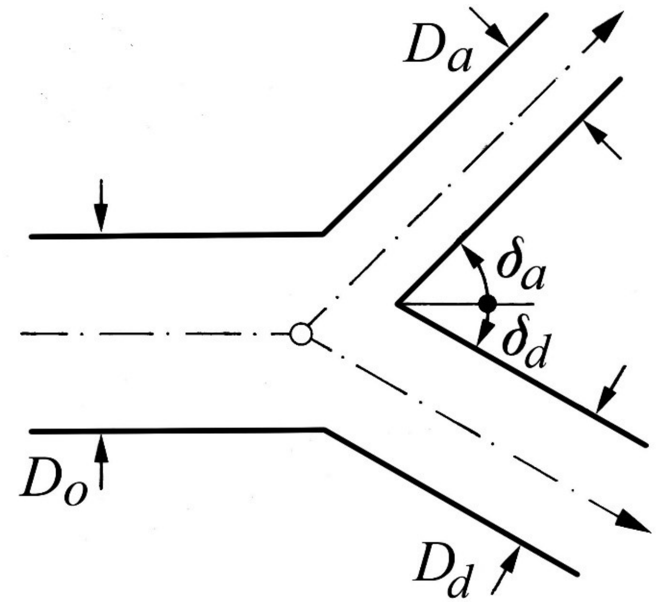
- Main branch straight δ_O=0°
- Lateral branch with δ_Z=90°
- m=n=1
- Rounded edges
- R_Z/b_Z variable



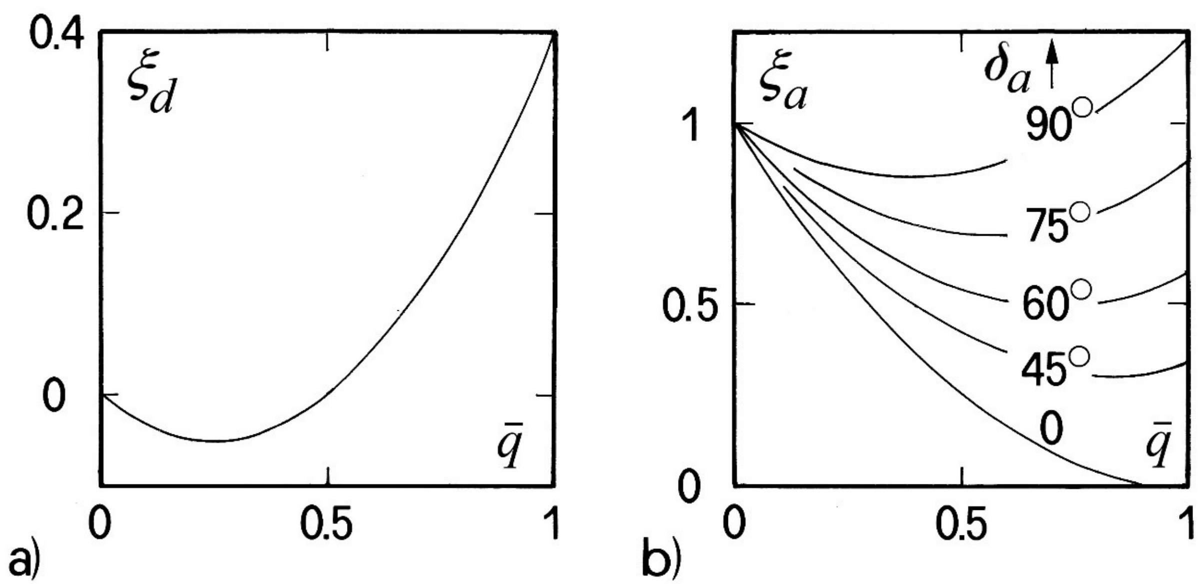
8.2 Sub-critical approach flow

Dividing junction

Main branch: Index *d*
Lateral branch: Index *a*
Inflow branch: Index o



- Main branch straight δ_o=0°
- m=n=1
- Sharp edges

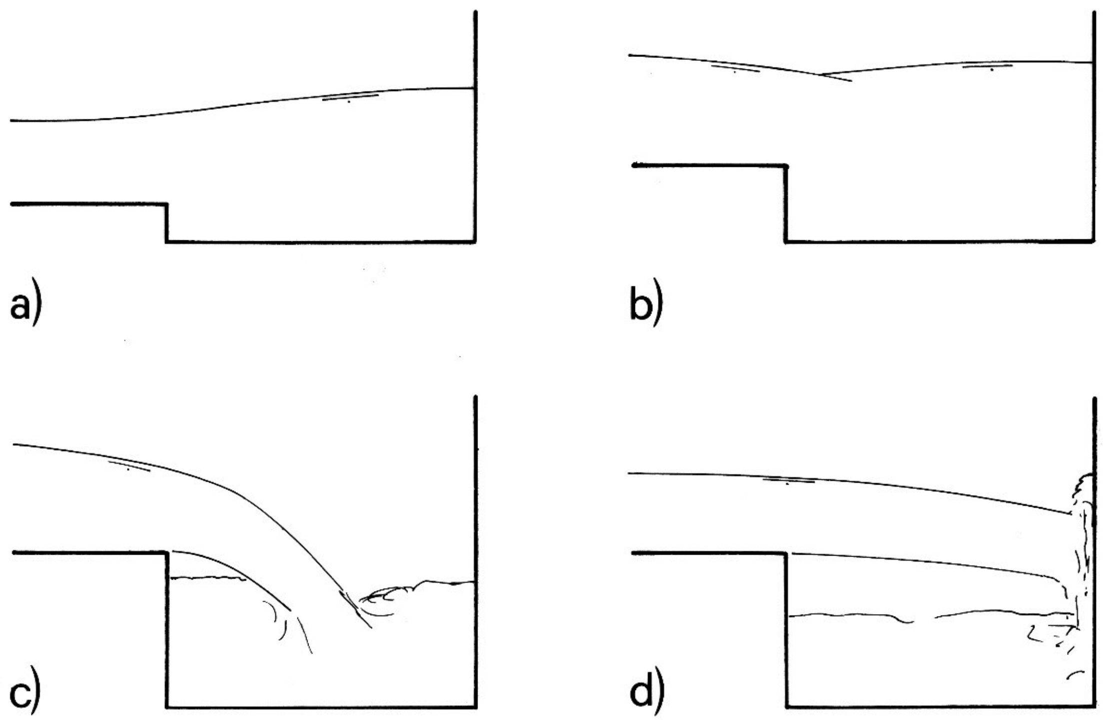


8.2 Sub-critical approach flow

Only for sub-critical flow conditions!

Bottom offset at lateral branch
To avoid backwater effect in lateral branch, only rarely used

(a) submerged, (b) plunging jet, (c) free jet, and (d) impingement at opposite wall



8.3 Super-critical flow design

8.3 Super-critical flow design

Several phenomena of super-critical flow affect the design of junction manholes, mainly because of stagnant **shock waves** at

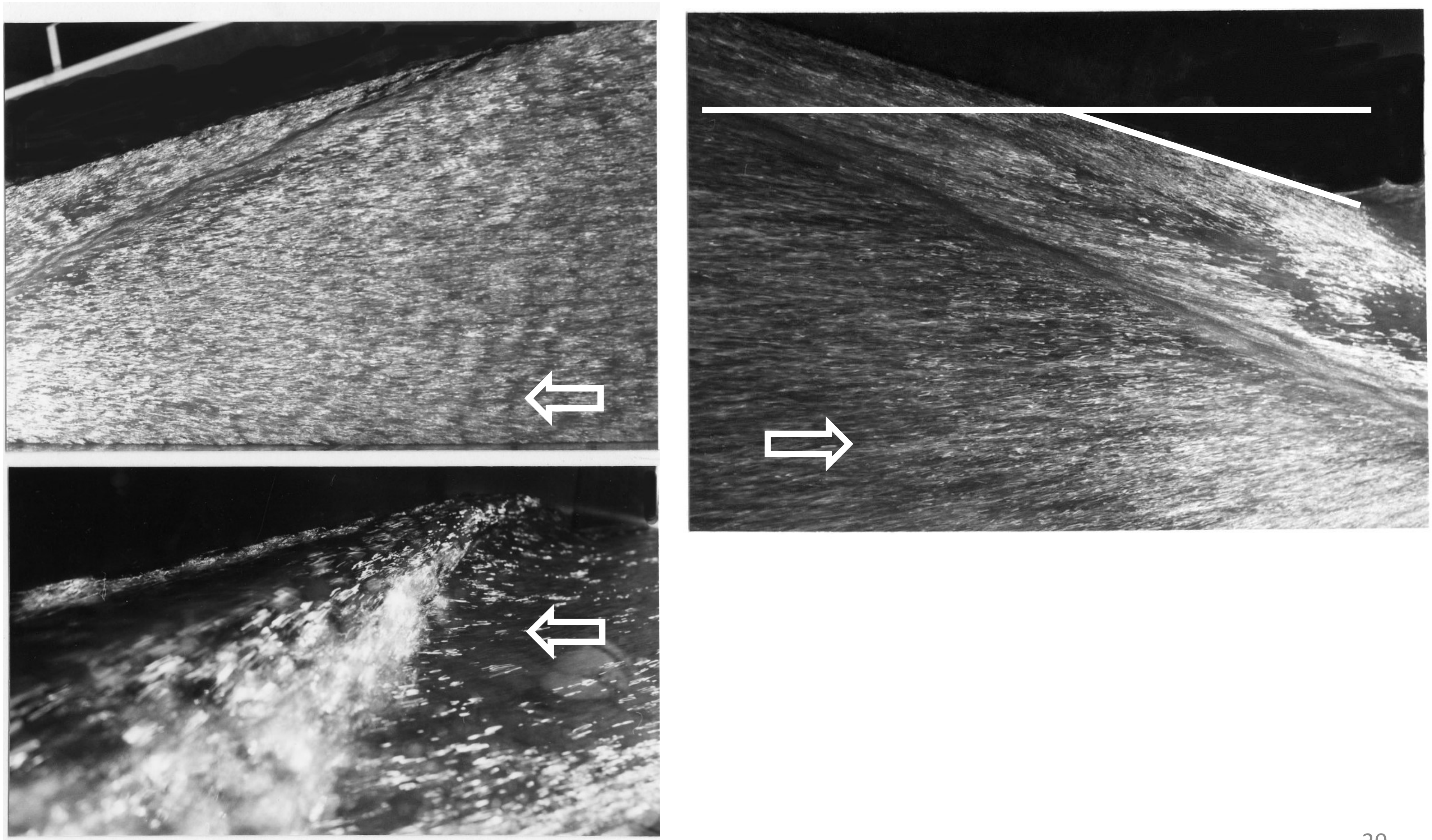
- abrupt wall deflection
- channel contraction
- channel bend
- standing waves

These phenomena are first characterized, then their impact on the junction manhole deign is explained

Flow disturbance ⇨ shock wave ⇨ failure of system

8.3 Super-critical flow design

Shock waves due to abrupt wall deflection (I) (Hager 2010)

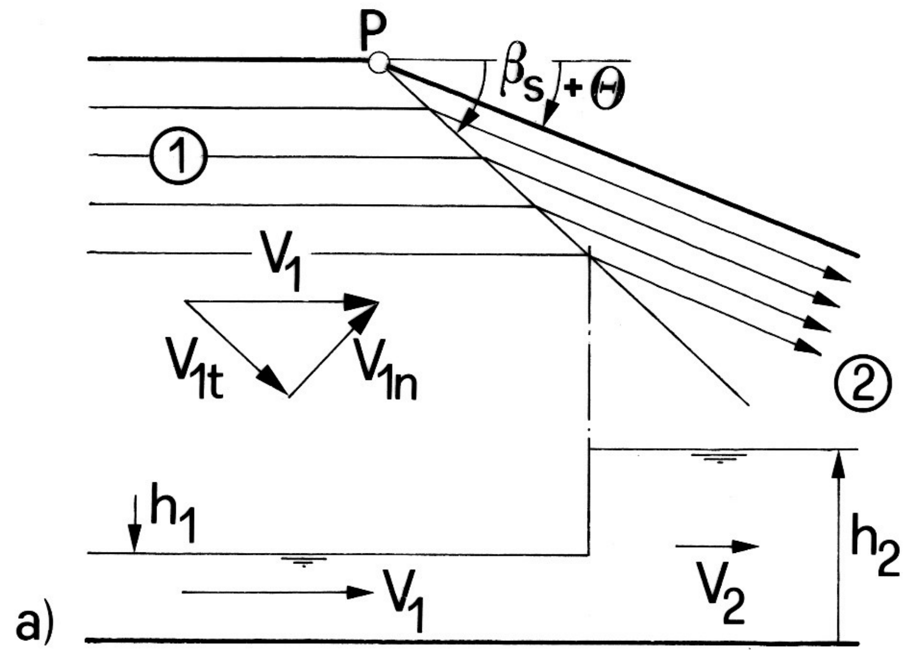


8.3 Super-critical flow design

Shock waves due to abrupt wall deflection (II) (Hager 2010)

Shock wave characteristics

Normalization:
$F_1=V_1/(gh_1)^{1/2}$ und $Y_s=h_2/h_1$



Shock number $S_1 = \mathsf{F}_1\theta$

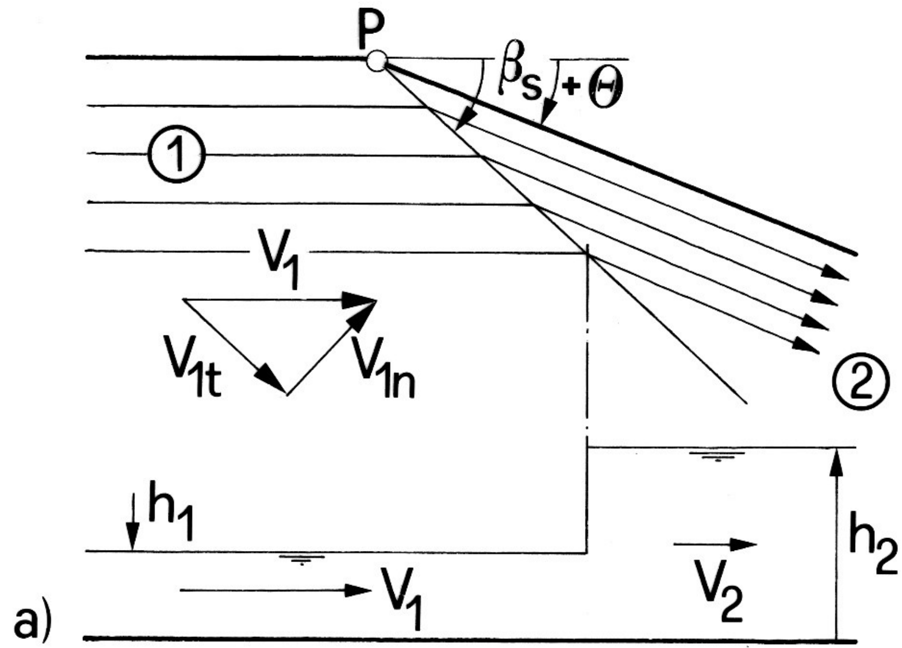
Depth ratio $Y_s = 1+\sqrt{2}S_1$

Shock angle $\frac{\beta_s}{\theta} = 1+1.06S_1^{-1}$

8.3 Super-critical flow design

Shock waves due to abrupt wall deflection (III) (Hager 2010)

Shock wave characteristics



Normalization:
$F_1 = V_1/(gh_1)^{1/2}$ und $Y_s = h_2/h_1$

Froude ratio $$\frac{F_2}{F_1} = 1 + \frac{S_1}{\sqrt{2}}$$

Maximum water depth along wall

$$\frac{h_{wM}}{h_1} = 1 + \sqrt{2} S_1 \left(1 + 0.25 S_1\right)$$

8.3 Super-critical flow design

Shock waves at conduit bend (Hager 2010)

Positive shock wave along external wall, negative shock wave along inner wall

Wave maxima at β, 2β, …

Bend number $B = \sqrt{\frac{b}{R}}\mathsf{F}_o$

Approximation of maximum/minimum wave height $y_e = \frac{h_M}{h_o} \cong \left(1 \pm 0.5B^2\right)^2$

Approximate location of maximum wave height $\tan\beta = \frac{b}{R}\mathsf{F}_o$

8.3 Super-critical flow design

Shock waves at rectangular channel junction (I) (Hager 2010)

Shock waves

For one active channel only

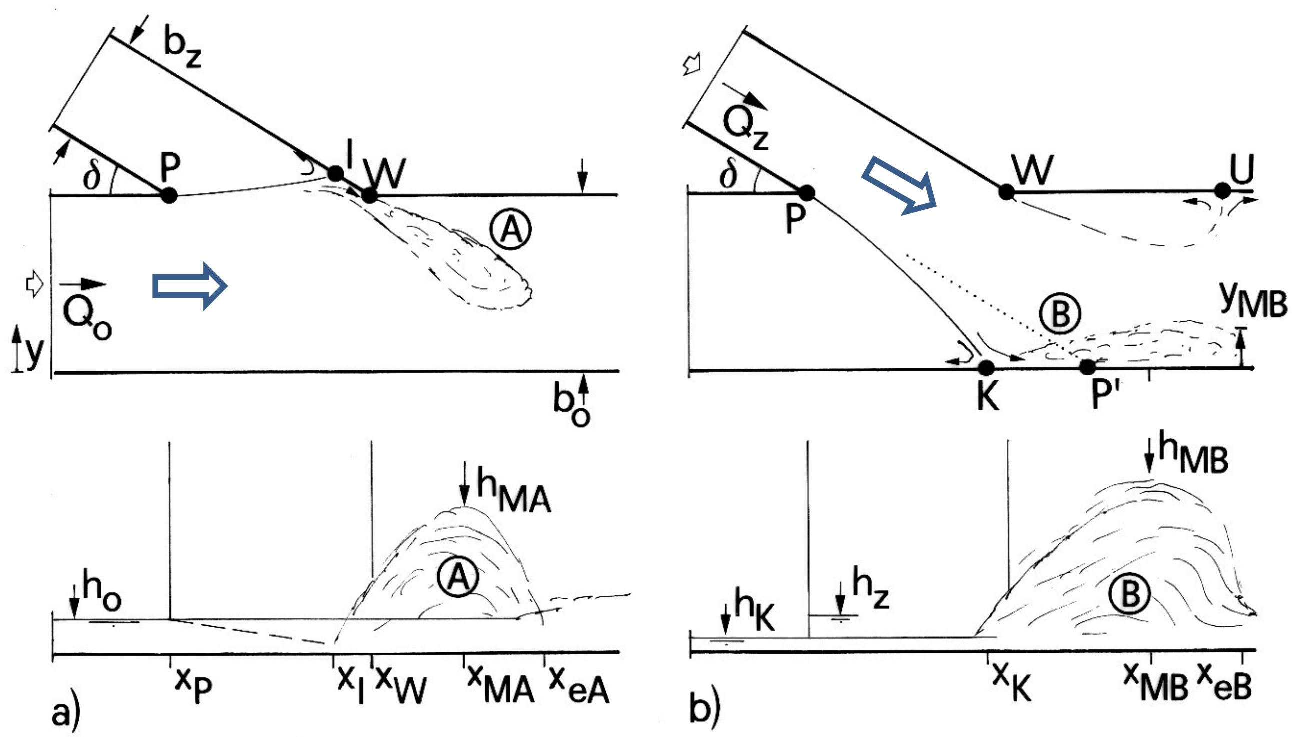
(no discharge in the other channel)

Geometry

- Straight main branch
- Horizontal
- Sharp edges

Discharge scenarios

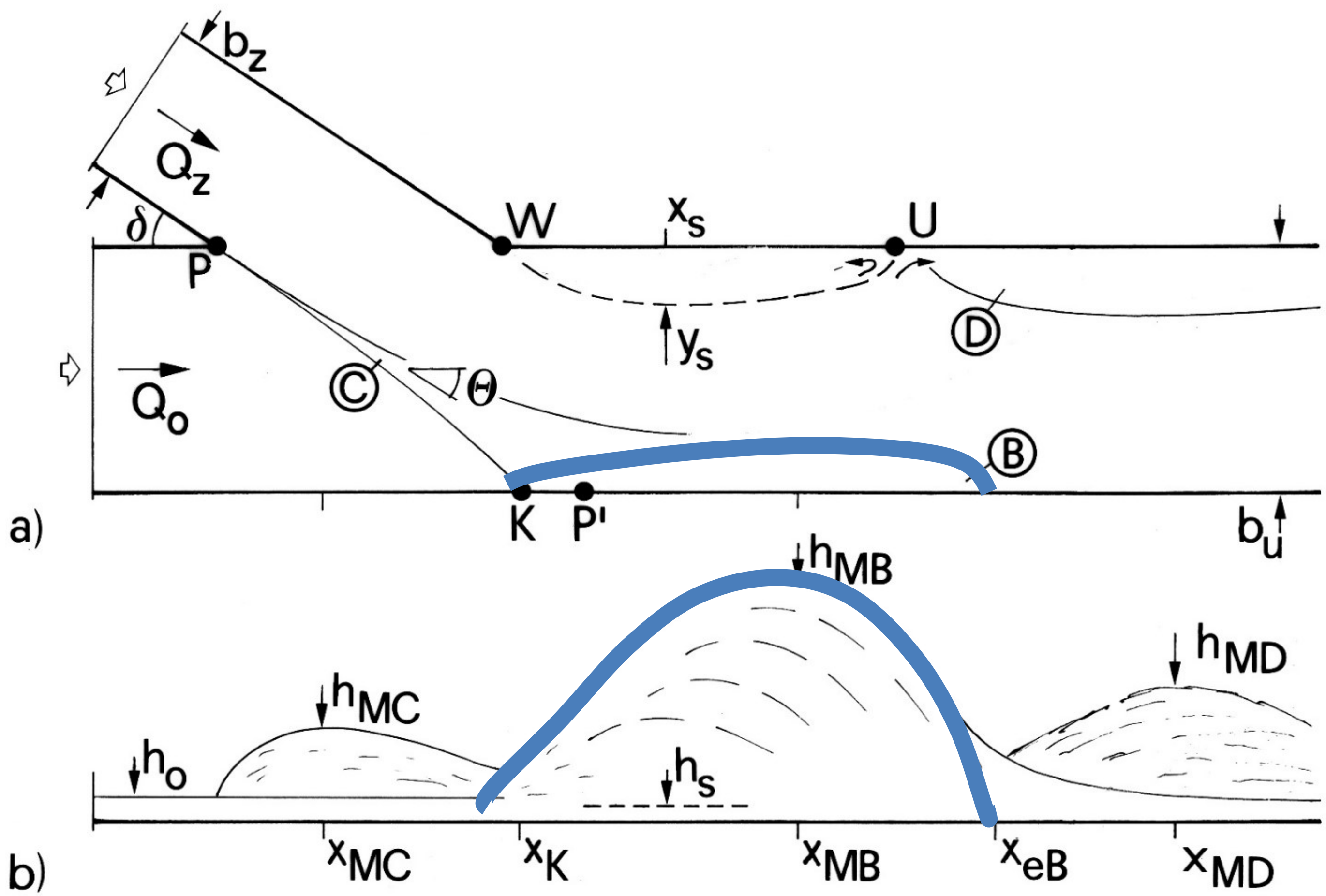
- Left: flow only in main channel
- Right: flow only in lateral channel



8.3 Super-critical flow design

Shock waves at rectangular channel junction (II) (Hager 2010)

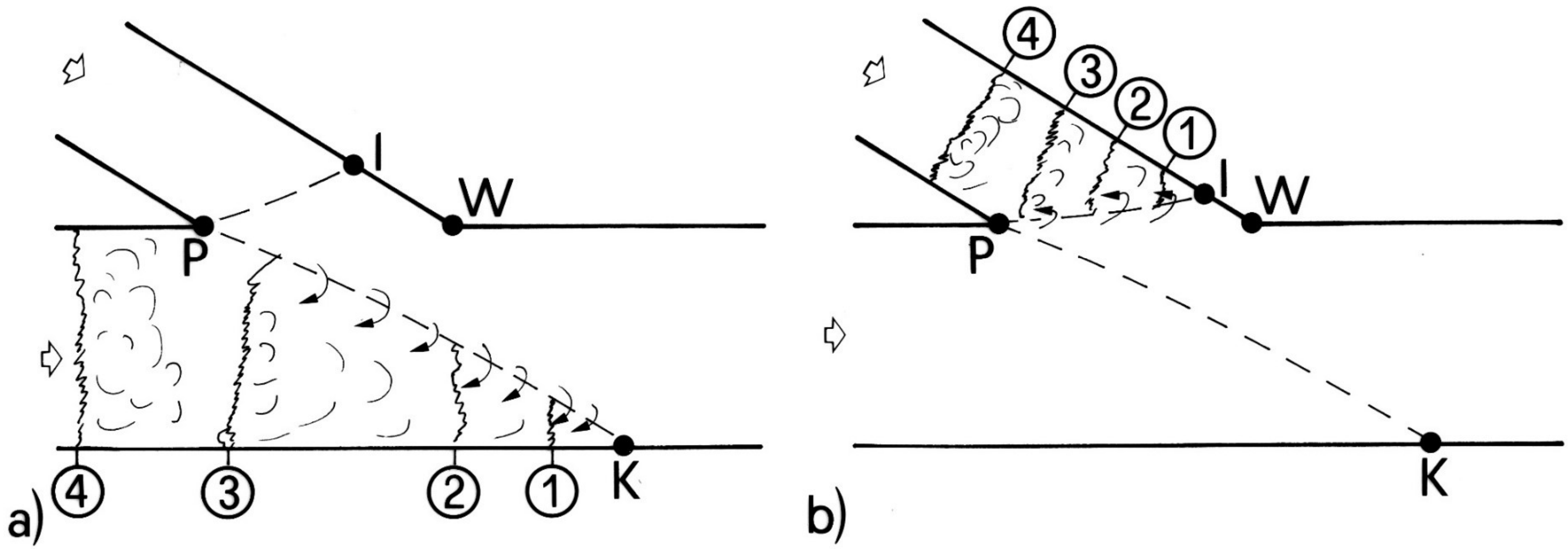
Both channels active: Shock wave B is highest and relevant for design (Hager 1999)



8.3 Super-critical flow design

Shock waves at rectangular channel junction (III) (Hager 2010)

Stagnant waves (limit condition): one branch sub-critical, one super-critical.
Hydraulic jump at transition

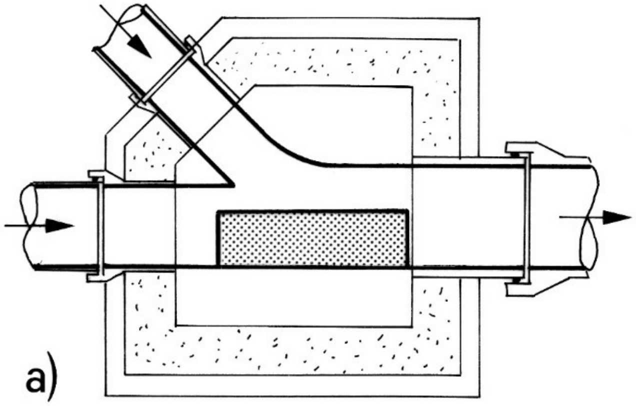


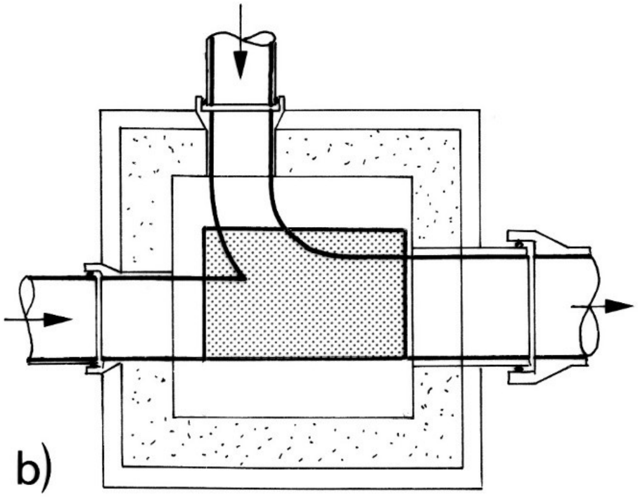
8.3 Super-critical flow design

Shock waves at conduit junction (I) (Hager 2010)

«Old» concept for super-critical flow:
Cover plate (up to 45°)

- Left case possible, right case unrealistic (choking)
- Only few experience, do preferably not apply
- Floating sediments get trapped at plate; they initiate choking (photo: floating objects blocked at valve)


a)


b)

8.3 Super-critical flow design

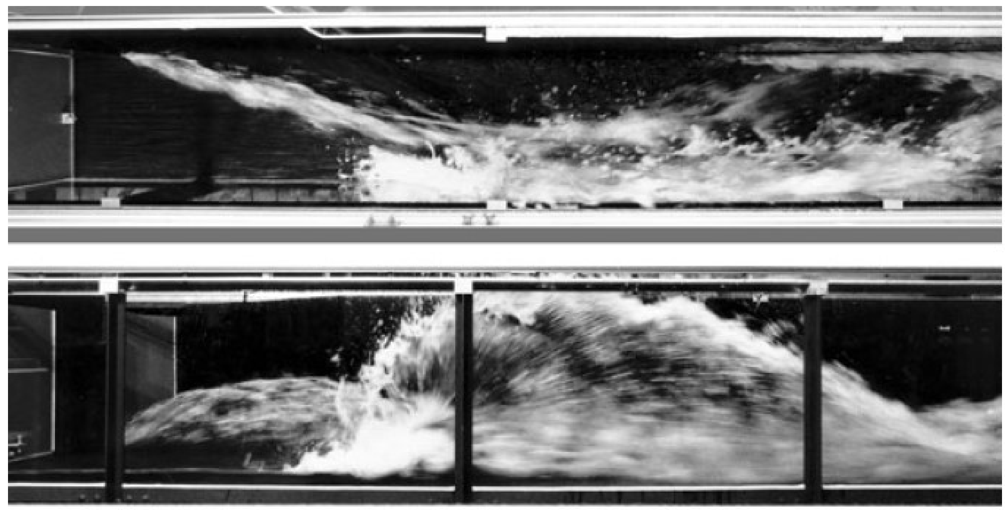
Shock waves at conduit junction (II) (Hager 2010)

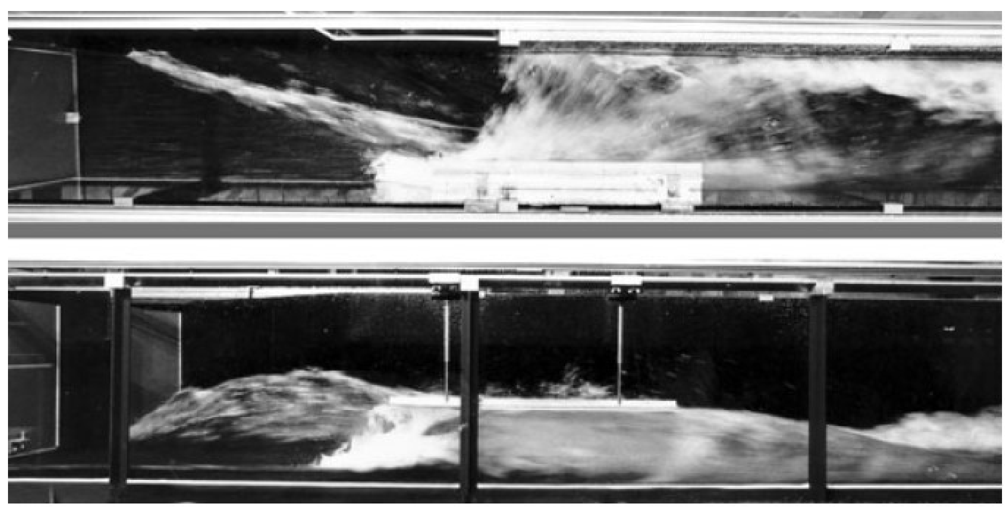
«Old» concept for super-critical flow: Cover plate (up to 45°)

Flow pattern

- Top: without cover plate
- Bottom: with cover plate

Photos for rectangular channel (Hager 1999)



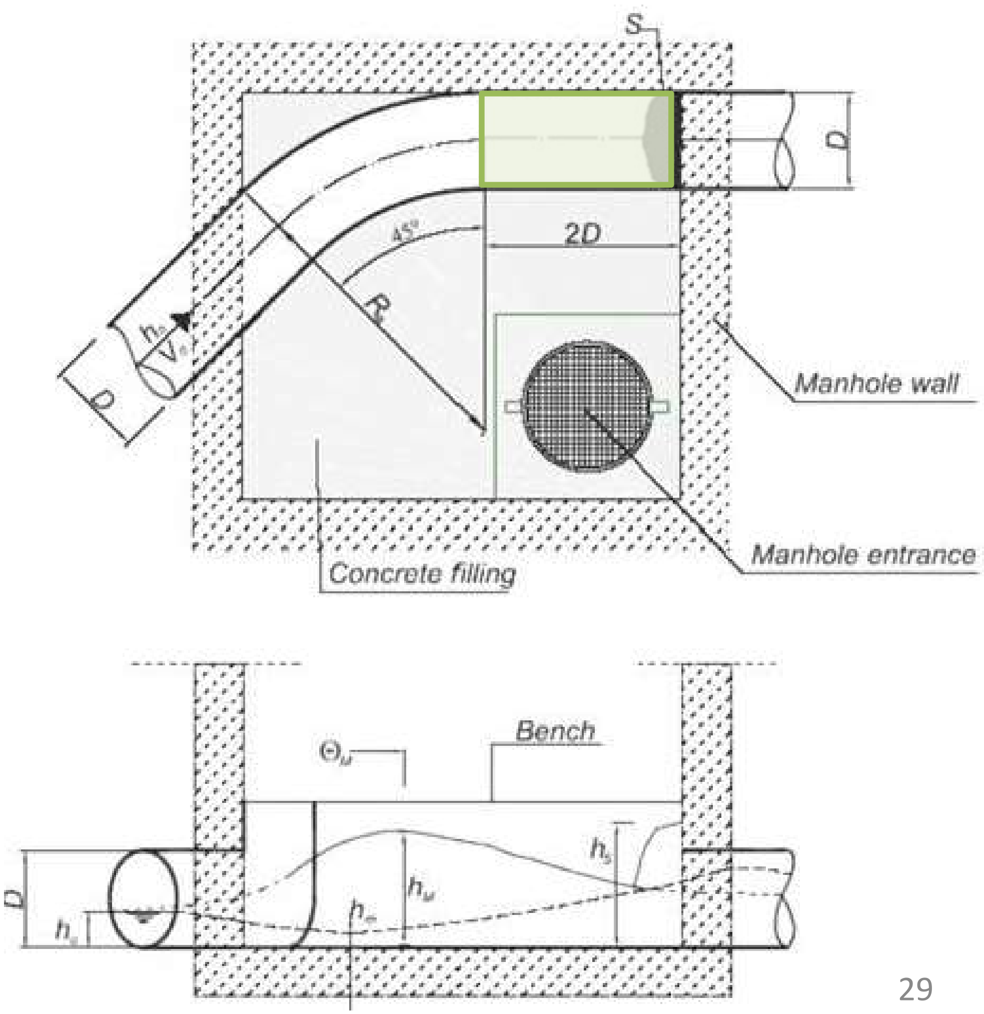


8.3 Super-critical flow design

Shock waves at conduit junction (III) (Hager 2010)

«Intermediate» concept for super-critical flow: Extension (after bend, lateral branch)

- *R*=3*D*
- Bench height 1.5*D*
- Maximum wave height at 35 to 55°, so that 45° bend is most sensitive
- Extension of straight 2*D* section d/s of bend
- 90° bend: intermediate, straight section with length *D*



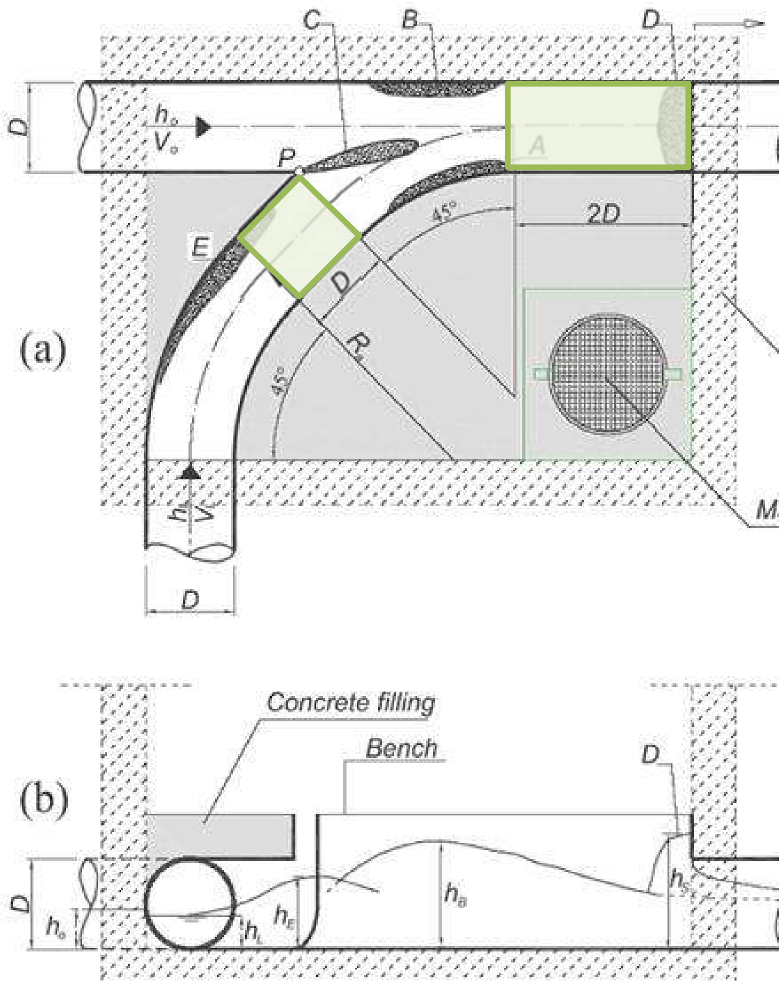
8.3 Super-critical flow design

Shock waves at conduit junction (IV) (Hager and Gisonni 2005)

«Intermediate» concept for super-critical flow: Extensions (in bend and at manhole end)

1. For bend > 45°: intermediate straight extension with length *D* at 45° upstream of junction point
2. Straight extension of 2*D* length downstream junction point but upstream of manhole end

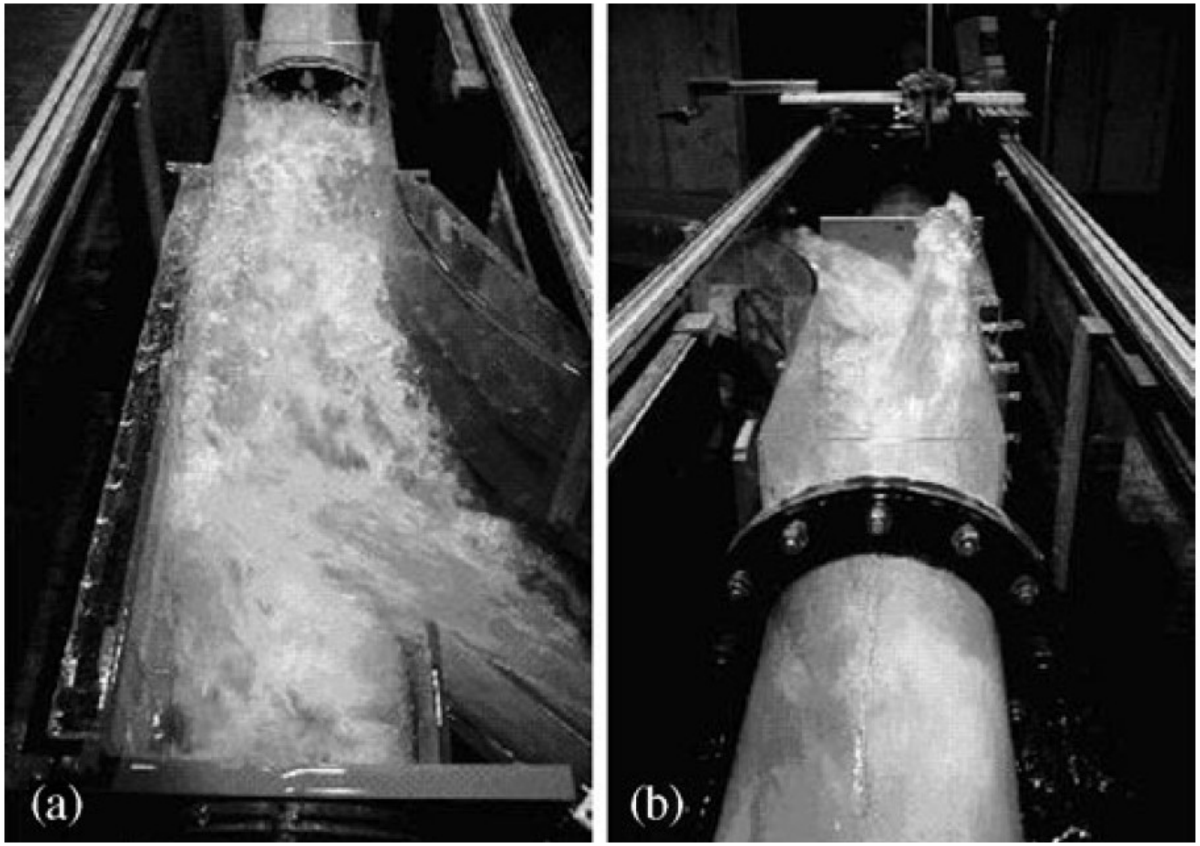
- *R*=3*D*
- Bench height 1.5*D*
- Over all extensions are *L*≈5*D* und *B*≈4*D*
- All conduits have same *D*



8.3 Super-critical flow design

Shock waves at conduit junction (V) (Hager and Gisonni 2005)

«Intermediate» concept for super-critical flow : wave "B" is relevant for design



8.3 Super-critical flow design

Shock waves at conduit junction (VI) (Hager and Gisonni 2005)

«Intermediate» concept for super-critical flow

Advantages

- Simple
- Reduced choking due to “lower” shock waves ⇨ high discharge capacity
- No cover plate

Disadvantages

- *D* is constant in all three branches = very rate in practice! (usually, downstream conduit requires larger *D*)
- Only for 45° or 90°
- Large manhole dimensions

8.3 Super-critical flow design

Shock waves at conduit junction (VII) (Hager and Gisonni 2005)

«Intermediate» concept for super-critical flow applies for control manhole, bend manhole and junction manhole

Hager & Gisonni (2005) give the manhole capacity *K* (sum of discharges from both branches), using the capacity-Froude number and the limit partial filling ratio:

$$\mathsf{F}_k = \frac{Q_k}{\sqrt{gD^5}} \qquad y_k = \frac{h_k}{D}$$

Capacity	Through-flow (control manhole)	Junction	Bend
y_K	0.75	0.70	0.65
F_K	2.0	1.4	0.8

8.3 Super-critical flow design

Shock waves at conduit junction (VIII) (Pfister et al. 2013,Crispino et al. 2019)

«New» concept for super-critical flow with variable *D* and θ

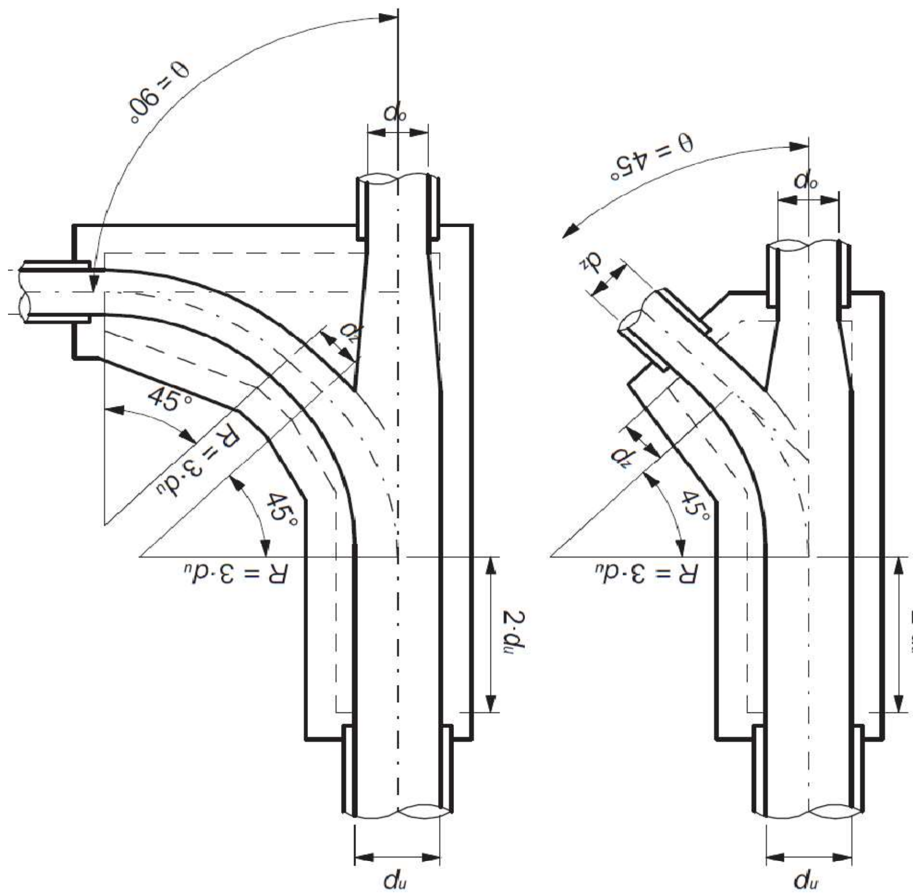
Systematical variation of D_i, F_i, Y_i and θ

- Compute uniform flow parameters at inflow branches
- Derive per inflow branch D_i, F_i, Y_i
- Derive the values

$$z_i = \frac{y_i}{d_i}$$

$$\beta_i = \frac{d_i}{d_U}$$

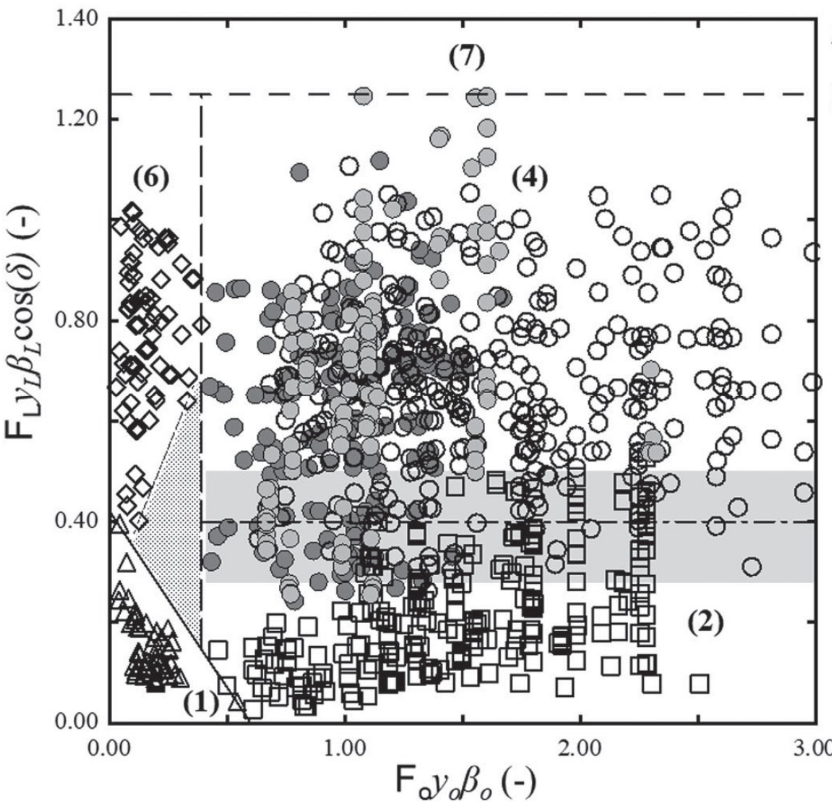
$$\mathrm{Fr}_i = \frac{Q_i}{\sqrt{g d_i y_i^4}}$$



8.3 Super-critical flow design

Shock waves at conduit junction (IX) (Pfister et al. 2013,Crispino et al. 2019)

«New» concept for super-critical flow



(1) subcritical flows entering junction manhole;
(2) supercritical straight branch and subcritical lateral branch;
(3) transitional to supercritical flow in both upstream branches;
(4) both upstream branches under supercritical flow conditions;
(5) choking either of lateral or straight branches;
(6) subcritical straight branch and supercritical lateral branch; and
(7) choking of downstream branch.

8.3 Super-critical flow design

Shock waves at conduit junction (X) (Pfister et al. 2013,Crispino et al. 2019)

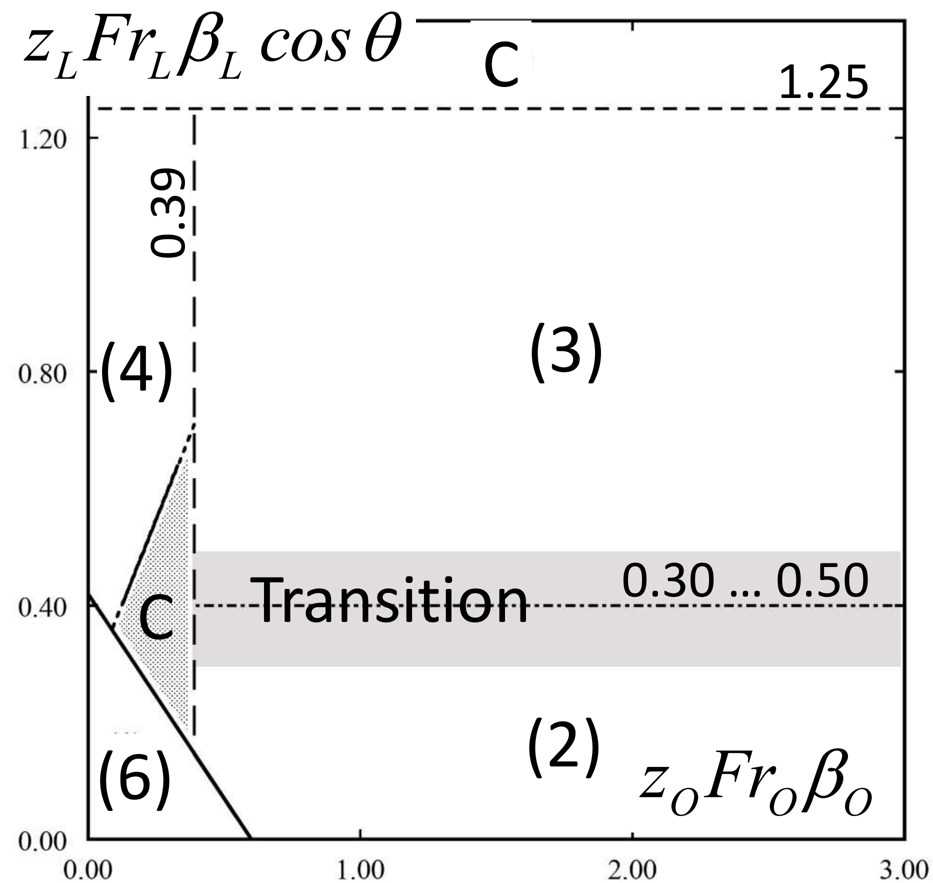
«New» concept for super-critical flow

Régimes d'écoulement :

1. torrentiel dans O et aucun débit dans L.
2. torrentiel dans O et fluvial L.
3. torrentiel dans les deux.
4. fluvial dans O et torrentiel dans L.
5. torrentiel dans L et aucun débit dans O.
6. (fluvial dans les deux=

«C» se réfère à l'étouffement

θ>45°? ➲ θ=45° dans diagramme



8.3 Super-critical flow design

Shock waves at conduit junction (XI) (Pfister et al. 2013,Crispino et al. 2019)

«New» concept for super-critical flow

La capacité Q_C est le débit maximum qui peut s'écouler à travers d'une jonction. Elle est exprimée par P_C

- Le débit effective Q_U=Q_O+Q_L est exprimé avec P_U

$$\mathsf{P}_U = \frac{Q_O + Q_L}{\sqrt{gD_U{}^5}} < \mathsf{P}_C = \frac{Q_C}{\sqrt{gD_U{}^5}}$$

- Pour le régime 3 (voir transparent précèdent)

$$\mathrm{P}_C = \frac{4}{5}\mathrm{F}_O\left(\frac{h_O{}^{6/5}}{D_U h_L{}^{1/5}}\right)(\sin\delta)^{0.3} - \frac{1}{3}$$

- Taux de remplissage aval pour le régime 3

$$Y_U = \frac{2\mathsf{P}_U}{\mathsf{F}_O Y_O \beta_O + \mathsf{F}_L Y_L \beta_L}$$

8.3 Super-critical flow design

Example

Une branche latérale *L* est dirigée dans branche droite *O.*

θ=90°

Q_O=1.09 m^3/s, D_O=0.75 m, J_{SO}=0.1

Q_L=0.78 m^3/s, D_L=0.75 m, J_{SL}=0.04

D_U=? m

8.3 Super-critical flow design

A similar case in the physical model…

8.3 Super-critical flow design

There are numerous junction types built, and they hardly follow theory…

(Stadt Zürich, Vereinigung und Entlastung in Regenbecken Werdinsel, Foto Tagesanzeiger 7.12.2018)

8.4 Pro memoria

8.4 Pro memoria

1. *Sub-critical flow:* simple geometry, consider losses and flow depths
2. *Super-critical flow:* chocking because of show waves

Sub-critical flow

- Energy losses known
- Energy loss estimations are only valid for $F<0.7$ and for pressurized flow
- Nevertheless, these are used for all junctions
- Loss coefficient may be negative!
- Compute flow depth for individual branches
- Bottom offset to avoid backwater

8.4 Pro memoria

Super-critical flow

- Shockwaves with hydraulic jump
- Wave formation in bend
- Consider maximum wave height at junction
- Concept of cover plate
- Concept of Hager & Gisonni

Note: New and general design equation are developed by LCH these days.

- Pfister (2013). Séminaire VSA/EPFL *Hydraulique des canalisations*
- Pfister and Gisonni (2014). Head losses in junction manholes for free surface flows in circular conduits. *Journal of Hydraulic Engineering*

Questions?