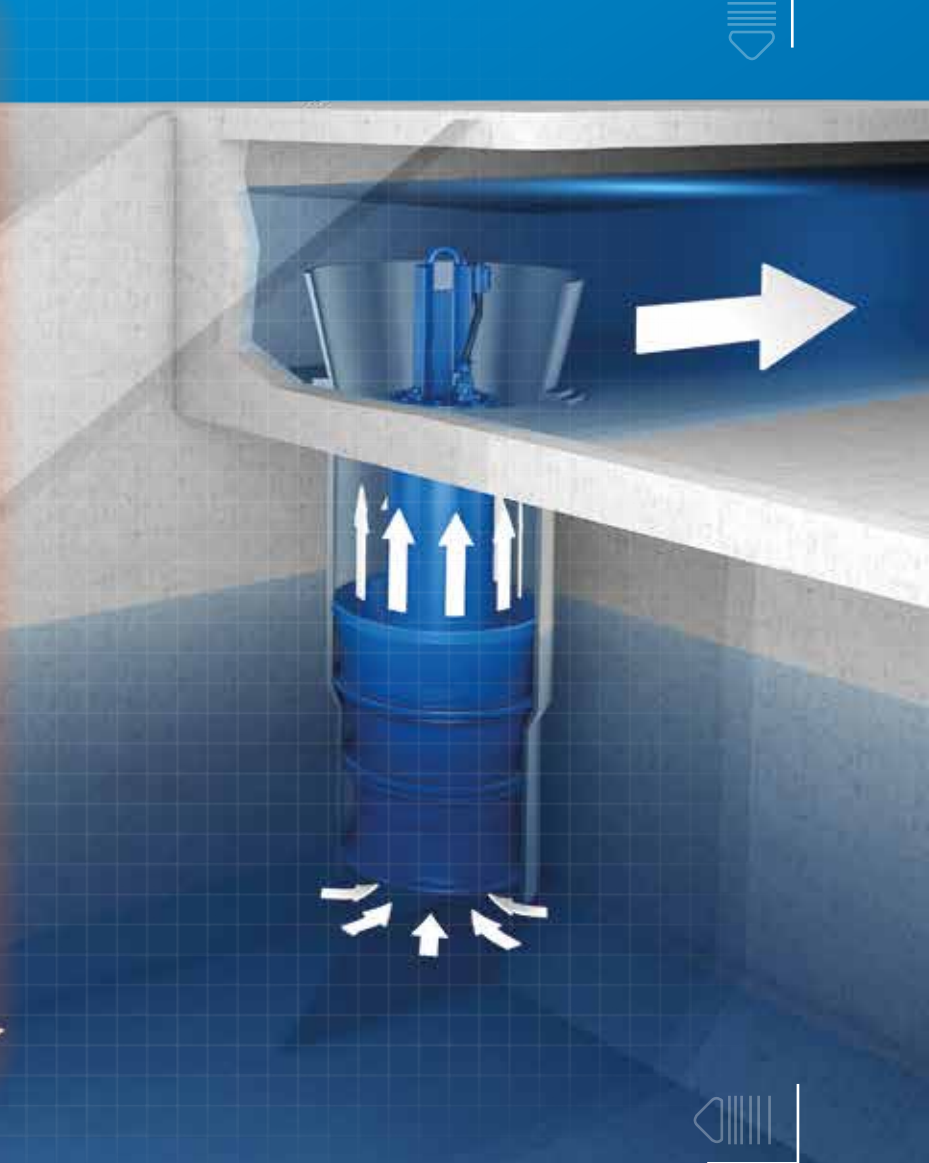


# KSB Know-how: Planning Information for Amacan Submersible Pumps in Discharge Tubes



**Dear Partners,**

Submersible motor pumps represent an economically viable technical alternative to conventional dry-installed pumps for water and waste water applications. They offer a number of handling advantages in terms of maintenance and installation work – an increasingly important factor as operating companies seek to cut back on staff.

Submersible motor pumps in discharge tubes also offer significant design advantages. For example, although they have the same hydraulic power as tubular casing pumps, submersible motor pumps are much more compact in size (no long shaft assemblies, no additional bearing locations in the discharge tube). Submersible motor pumps also require no additional buildings to accommodate their electric motors as these are directly mounted on the pump and installed in the discharge tube.

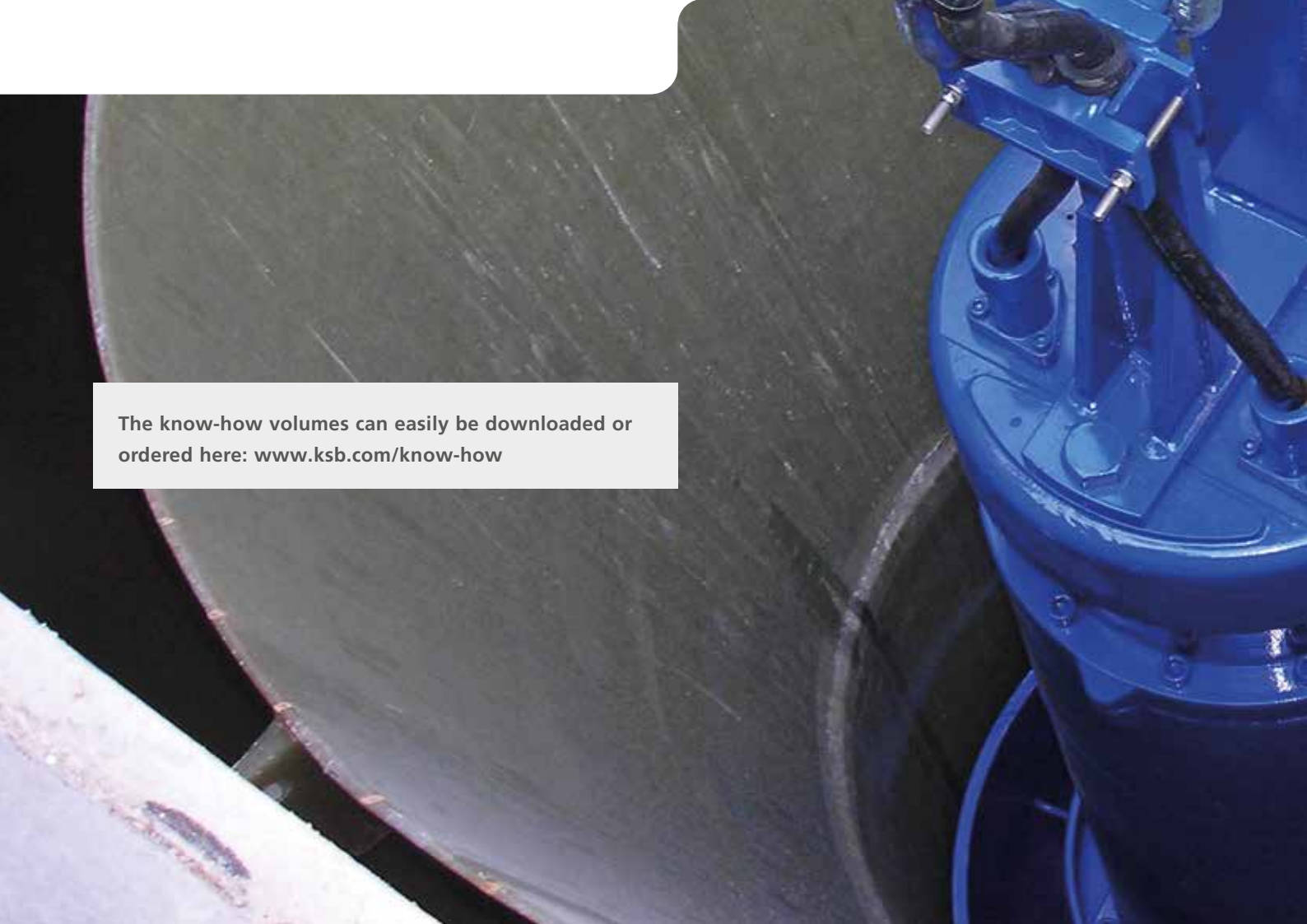
More and more operators are being won over by these advantages – KSB's Amacan pumps work in irrigation and drainage pumping stations, water works, sewage treatment plants, power stations, industrial water supply, water pollution and flood control.

They handle raw and clean water (groundwater, stormwater, river water) as well as mechanically pre-treated waste water and activated sludge.

More so than with other pumps, the construction and design of the periphery – i.e. the pumping station as a whole – play an important role in ensuring that submersible pumps in discharge tubes operate economically and reliably.

In addition to the selection of the pump's hydraulic system, this brochure will cover the design of pumping stations and provide in-depth information on pump installation planning and the design of the pump sump. Key points relating to electrical equipment will also be discussed.

This brochure is primarily aimed at consultants and operators in the water and waste water sectors.



The know-how volumes can easily be downloaded or ordered here: [www.ksb.com/know-how](http://www.ksb.com/know-how)

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# The Amacan Series

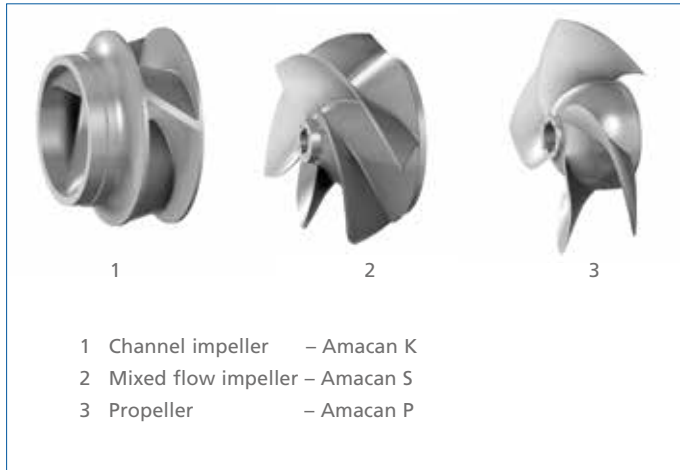


Fig. 1: Available impeller types for Amacan pumps



Fig. 2: Installation of a submersible motor pump with a mobile crane



Fig. 3: Building accommodating pumping station

## Impeller types and performance ranges

Wherever higher volume flow rates have to be handled, submersible motor pumps in discharge tube design have proved their worth in a wide range of applications. These submersible motor pumps can be optionally fitted with three different impeller types (see Fig. 1) enabling them to deal with a wide variety of fluids – from grey water, which is reasonably clean, right up to waste water or activated sludge (see Table 1). Selecting the right impeller type for a particular application will depend upon the nature and composition of the fluid handled and the pumping task.

Fluids handled	Notes and recommendations
Waste water	<ul style="list-style-type: none"> <li>Check the free passage through the impeller</li> <li>Pre-cleaned via a screen or weir</li> </ul>
River water	<ul style="list-style-type: none"> <li>Pre-cleaned via screen or shingle trap</li> </ul>
Storm water / waste water	<ul style="list-style-type: none"> <li>Check the free passage through the impeller</li> <li>Pre-cleaned via a screen or weir</li> <li>Propeller may necessitate a special casing wear ring</li> </ul>
Activated sludge	<ul style="list-style-type: none"> <li>Max. 2 % dry solids content</li> </ul>
Seawater	<ul style="list-style-type: none"> <li>Check possible material combinations or fit anodes with six-monthly check-ups</li> </ul>

Table 1: Notes and recommendations for different fluids handled

The selection charts in Figs. 5, 7 and 9 for the different impeller types show which sizes of a chosen pump series are suitable for the pumping task in question. When making a selection, it is not only important to be aware of which impeller type is the right match for the fluid handled, in some cases additional requirements in the design of the pumping station and the choice of the technical equipment must be observed for certain impeller types.

The design configuration of modern submersible motor pumps installed in discharge tubes has a number of advantages over that of conventional tubular casing pumps. For example, although they have the same hydraulic power (impeller) as tubular casing pumps, submersible motor pumps installed in discharge tubes are much more compact in size (no long shaft assemblies, no additional bearing locations in the discharge tube). The handling of a submersible motor pump is significantly more straightforward, simplifying in particular maintenance and installation.

Buildings to accommodate electric motors or ventilation equipment for heat dissipation are not required. The drive is an integral part of the submersible motor pump and contained in the discharge tube. For assembly and maintenance work on conventional pumps it is generally common practice to install large lifting equipment, the size of which will depend on the on-site installation depth. This lifting equipment represents a major investment even though it is only periodically used for repair work or pump installation/removal. In contrast, Amacan submersible motor pumps can be handled using mobile cranes, which are far more cost-effective. In order to fully exploit this advantage, appropriate access must be factored in at the planning stage.



Fig. 4: Photo and cross-section of Amacan K

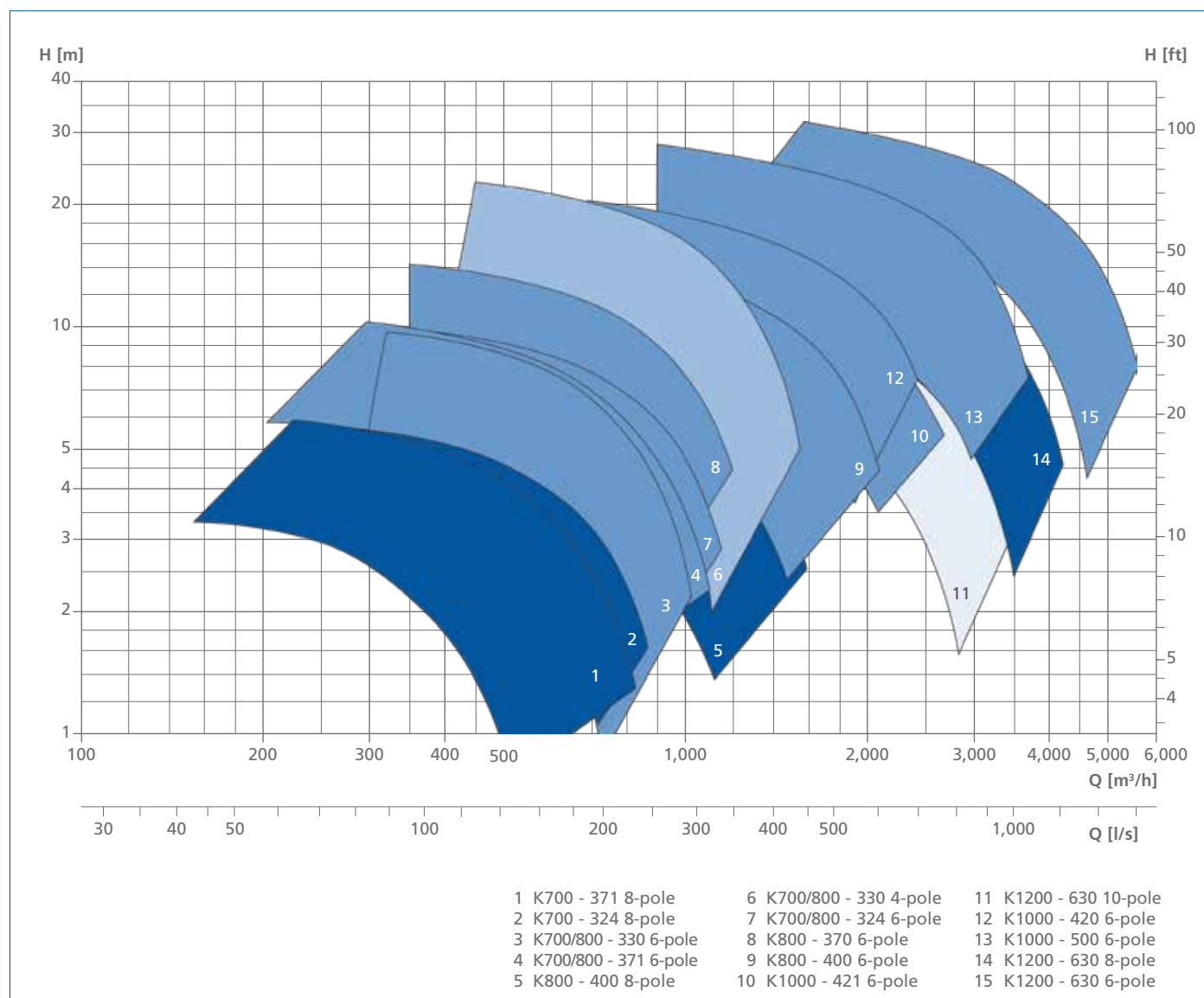


Fig. 5: Selection chart Amacan K (50 Hz)



Fig. 6: Photo and cross-section of Amacan S

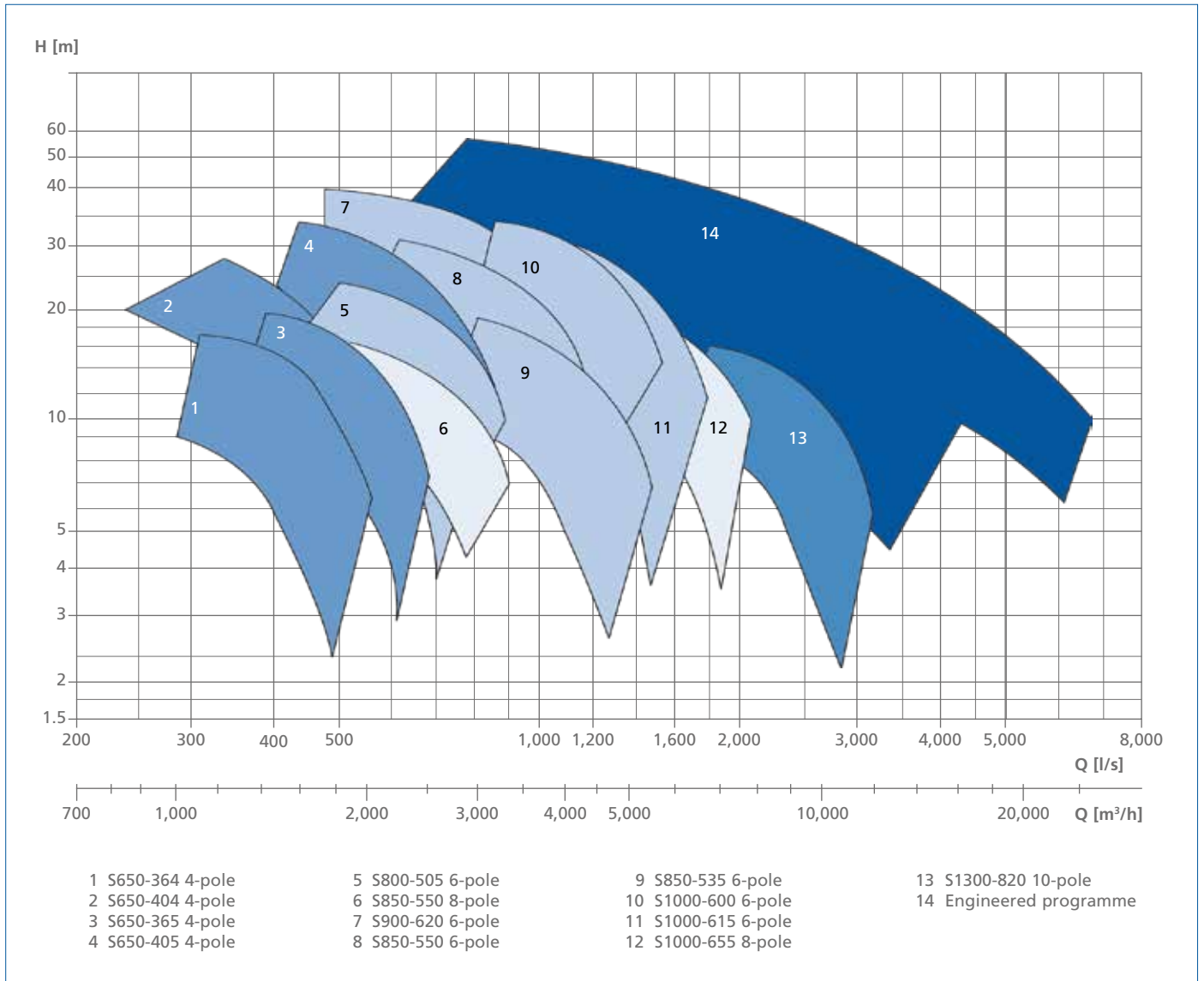


Fig. 7: Selection chart Amacan S (50 Hz)



Fig. 8: Photo and cross-section of Amacan P

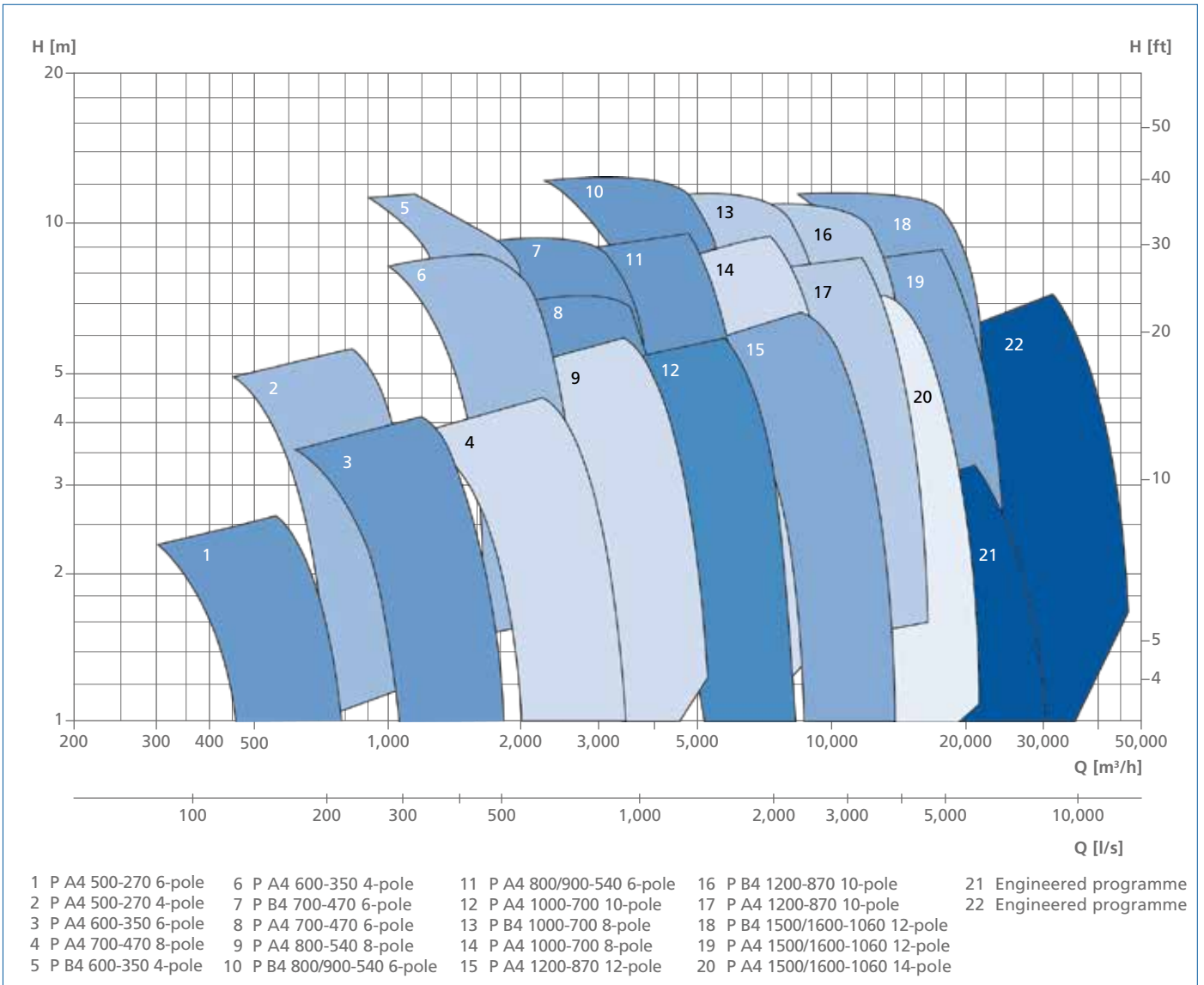


Fig. 9: Selection chart Amacan P (50 Hz)

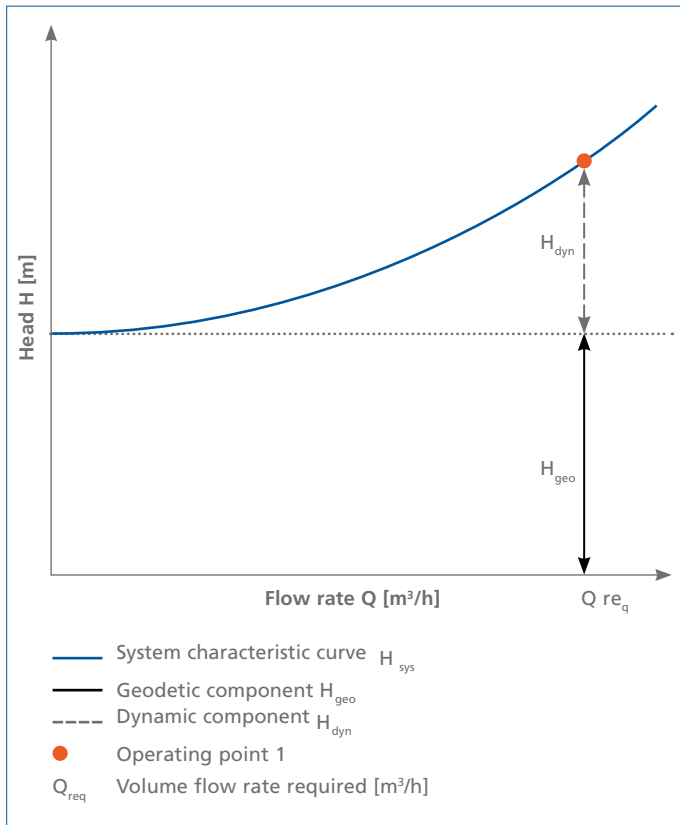
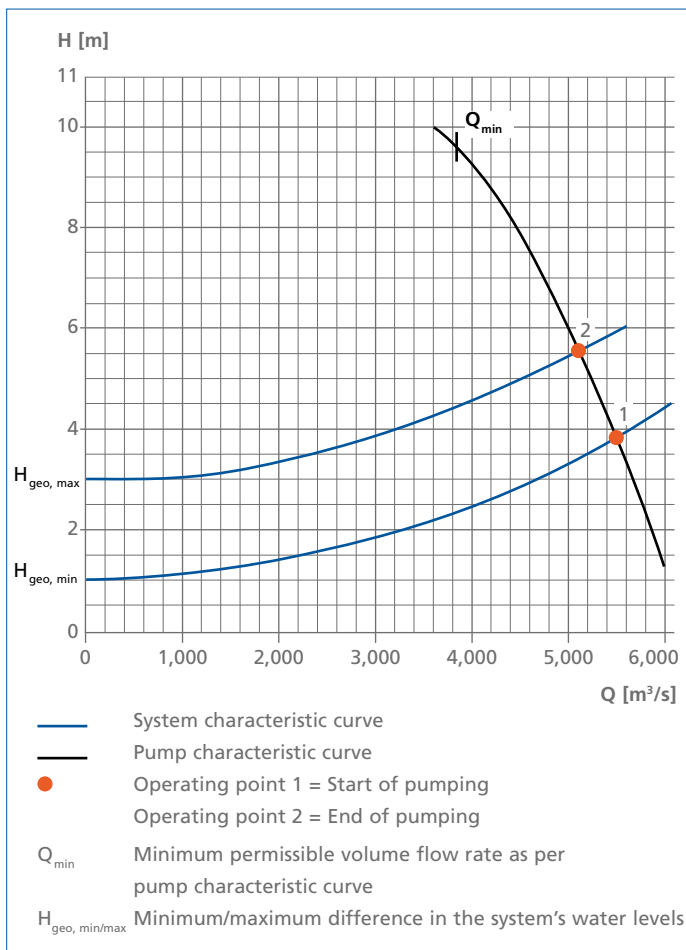
Fig. 10: Example of a system characteristic curve [ $H = f(Q)$ ]

Fig. 11: Illustration of possible water levels

## Calculation of operating points

With Amacan pumps, the manometric head required for a certain volume flow rate will be calculated using the same approach as with any centrifugal pump.

The documented pump characteristic curves already include the internal losses between the impeller inlet and 0.5 m downstream of the motor. Inlet and discharge tube losses upstream and downstream of these points, the head losses through flow deflection, fittings (valves etc.) and the outlet comprise the dynamic head component and must be taken into account.

The system curve comprises the geodetic head component (difference in water levels) and the dynamic head component (friction loss in pipes and fittings):

$$H_{total} = H_{geo} + H_{dyn} \quad [m] \quad \text{Formula (1)}$$

Key:

$H_{total}$  = Total head [m]

$H_{geo}$  = Geodetic height [m]

$H_{dyn}$  = Dynamic head component [m]

$$H_{dyn} = \sum_{i=1}^{i=n} \lambda_i \cdot \frac{L_i}{d_i} \cdot \frac{v_i^2}{2g} + \sum_{i=1}^{i=n} \xi_i \cdot \frac{v_i^2}{2g} \quad [m] \quad \text{Formula (2)}$$

Key:

$H_{dyn}$  = Dynamic head component [m]

$i$  = Index of pipe/fitting considered ( $i = 1$  to  $n$ )

$\lambda_i$  = Pipe friction factor

$L_i$  = Length of piping section  $i$  [m]

$d_i$  = Diameter of piping section  $i$  [m]

$\xi_i$  = Loss coefficient of piping section  $i$

$v_i$  = Flow velocity in partial section  $i$  [m/s]

$g$  = Acceleration due to gravity = 9.81 m/s<sup>2</sup>

As propeller pumps in particular often generate only a low head, the loss of head at the pipe outlet (a check valve is often installed!) must be considered in the calculation. When establishing the geodetic head component, the maximum differences between the suction and discharge side liquid levels of the pumping station are of interest, especially in low-lift pumping stations. During pump selection, these maximum water levels should not lead to unacceptably low or high pump heads, as this would mean that the pump is operating to the left of  $Q_{min}$  or to the right of  $Q_{max}$ .

If some loss coefficients  $\xi_i$  for calculating the system's dynamic head components are unknown, further information can be found in the Centrifugal Pumps Lexicon [www.ksb.com/centrifugal-pump-lexicon](http://www.ksb.com/centrifugal-pump-lexicon) using the search term "Loss coefficient / Head loss"



When selecting pumps installed in discharge tubes particular attention must be paid to the difference in water levels, as the minimum water level  $W_{l, \min}$  in the pumping station must not drop below the water level  $t_1$  required for the pump's volume flow rate. This is the only way to avoid surface vortices. The necessary depth  $t_{ps}$  of the pumping station can also be calculated using this water level. The minimum water level is a function of the volume flow rate required of the pump [ $t_1 = f(Q)$ ] and also of the intake chamber design (see information from page 21 onward).

In addition to the fluid level above the impeller (dependent on size) and the water level limit to prevent air-entraining vortices (dependent on volume flow rate) – both are illustrated in Fig. 12 – the NSPH of the pump at the operating point is relevant for determining the required water level  $t_1$ . The following condition must be fulfilled:

$$NPSH_{\text{available}} \geq NPSH_{\text{required}} + \text{safety allowance} \quad [\text{m}]$$

Formula (3)

**Key:**  
 $NPSH_{\text{available}}$  = Net positive suction head of the system [m]  
 $NPSH_{\text{required}}$  = Net positive suction head of the pump [m]  
 The safety allowance for water is approx. 1.0 m.

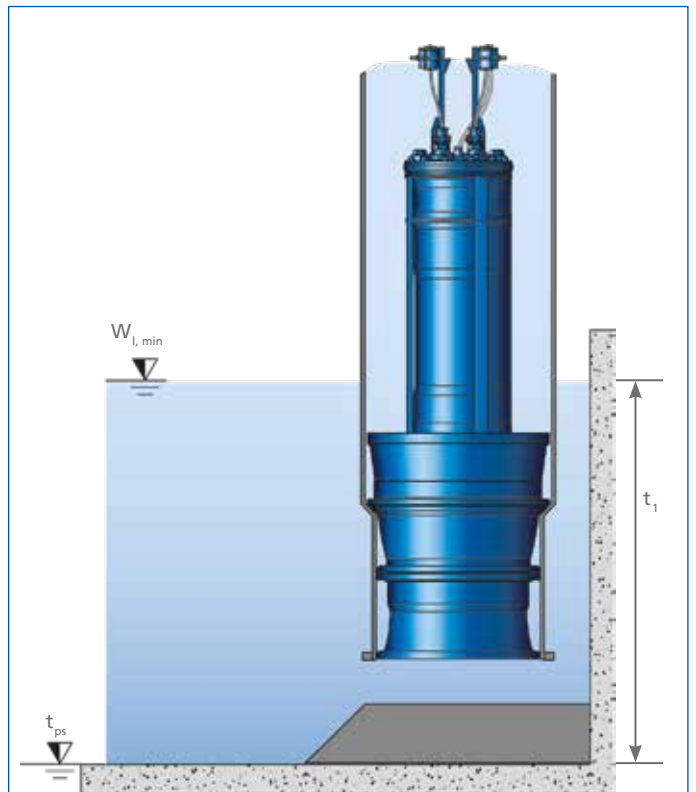
If this condition is not fulfilled, the value for  $t_1$  must be increased by the value of the difference.

$$t_{ps} = W_{l, \min} - t_1 \quad [\text{m}]$$

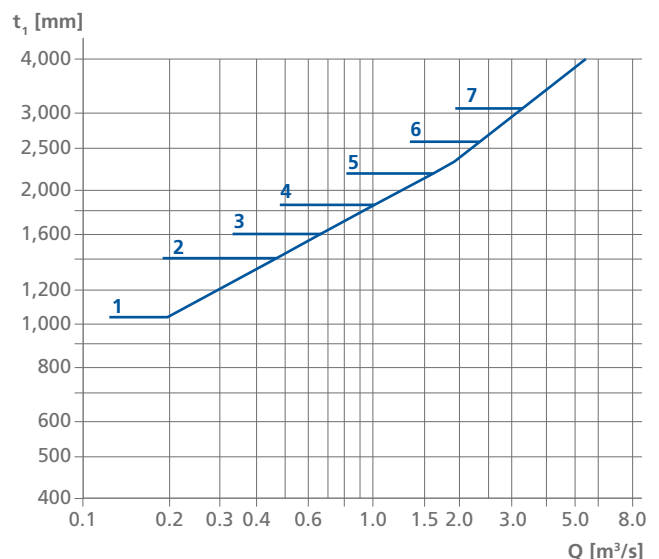
Formula (4)

**Key:**  
 $t_{ps}$  = Required pumping station depth [m]  
 $W_{l, \min}$  = Minimum water level in pumping station [m]  
 $t_1$  = Required water level for the pump's volume flow rate [m]

Should the discharge tube be open at the top (free overflow from the tube, for instance) then the overflow head  $h_{\text{overfl}}$  must be taken into account when calculating the total pump head  $H_{\text{tot}}$ . If there is no other data available, then the overflow head  $h_{\text{overfl}}$  can be taken from diagram 14.



$W_{l, \min}$  = Minimum water level in pumping station  
 $t_1$  = Required water level for the pump's volume flow rate  
 $t_{ps}$  = Required pumping station depth



- 1 Amacan P ... 500 – 270
- 2 Amacan P ... 600 – 350
- 3 Amacan P ... 700 – 470
- 4 Amacan P ... 800/900 – 540
- 5 Amacan P ... 1000 – 700
- 6 Amacan P ... 1200 – 870
- 7 Amacan P ... 1500/1600 – 1060

Fig. 12: Calculation of the minimum water level  $t_1$  for Amacan P (refer to the respective type series booklets for Amacan K and Amacan S)

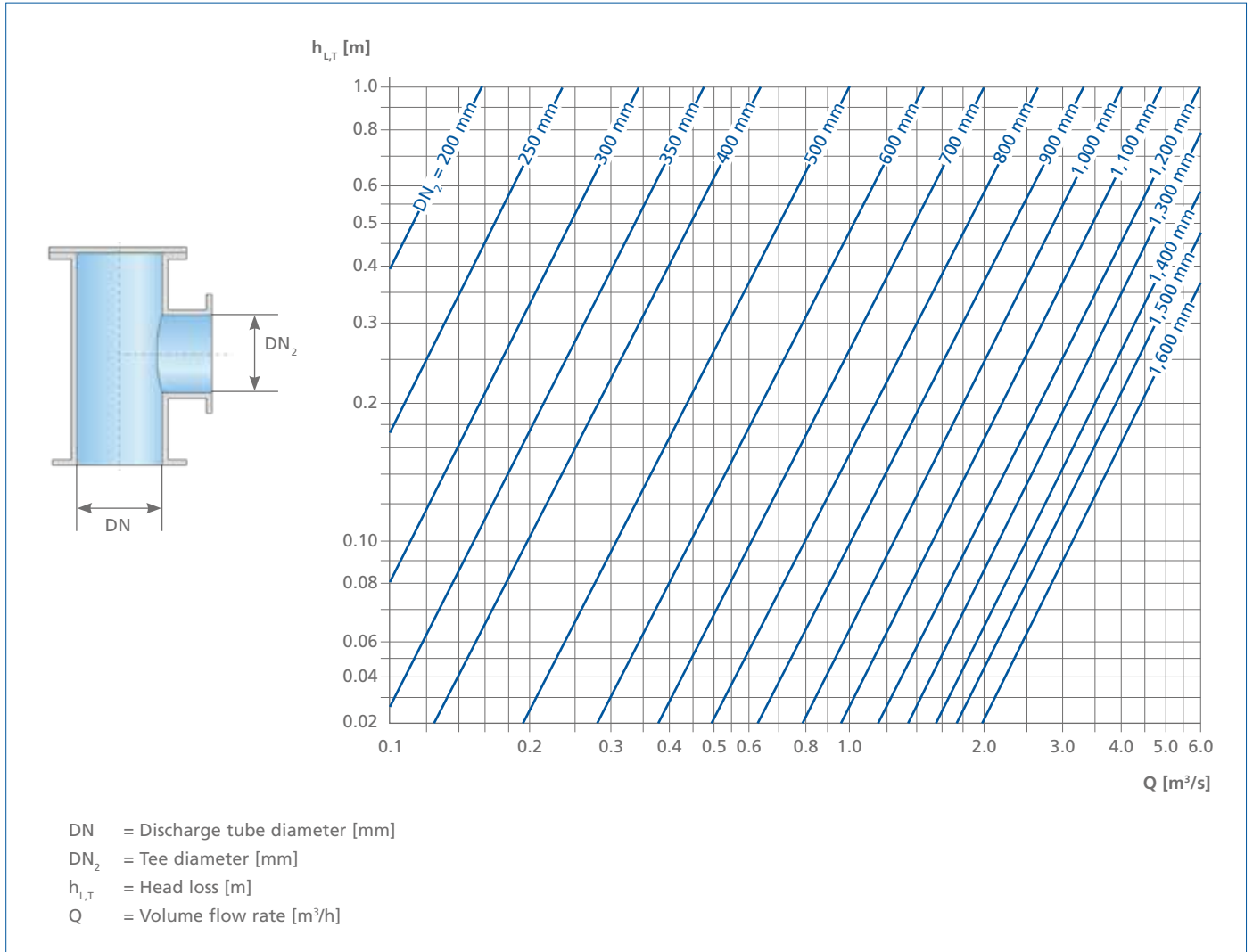


Fig. 13: Determining the head loss in a tee

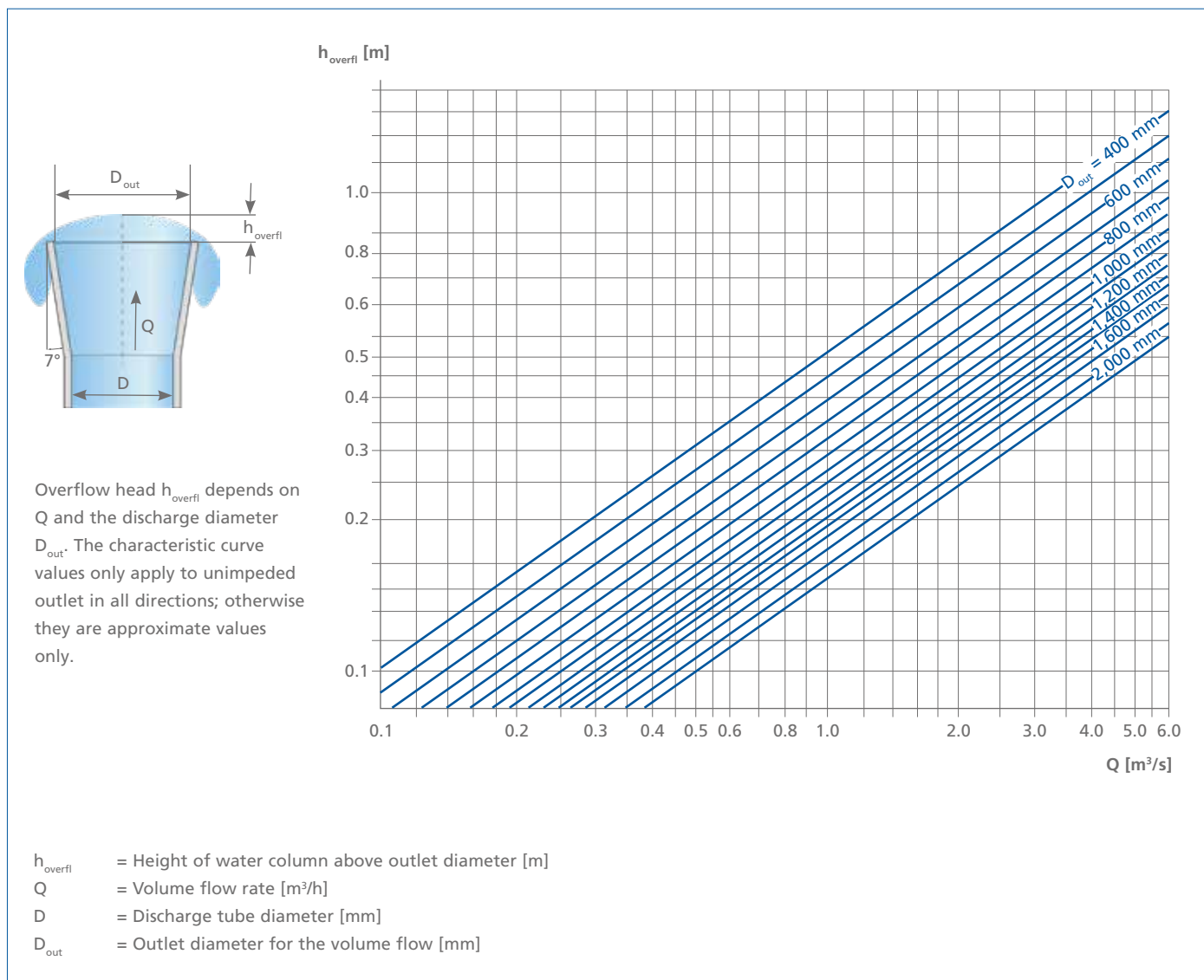


Fig. 14: Determining the overflow head  $h_{\text{overfl}}$

After the system curve has been determined, this should always be plotted together with the pump characteristic curve in order to check the operating points (curve intersections). In this way, the designer can ensure that no operating conditions outside the permissible section of the characteristic curve arise (Fig. 15).

---

**Note:**

Compare the  $t_1$  tables in the type series booklets for the respective sizes, features and corresponding volume flow rates.

---

**Given:**

- 1st duty point:
  - Flow rate  $Q_{\max} = 5,220 \text{ m}^3/\text{h} = 1,450 \text{ l/s}$
  - Head  $H = 5 \text{ m}$
  - Geodetic head  $H_{\text{geo,max}} = 2 \text{ m}$
- 2nd duty point:
  - Flow rate  $Q_{\min} = 4,932 \text{ m}^3/\text{h} = 1,370 \text{ l/s}$
  - Head  $H = 6.1 \text{ m}$
  - Geodetic head  $H_{\text{geo,max}} = 3.5 \text{ m}$
- Pump operating range:  $Q_{\min}$  to  $Q_{\max}$
- Fluid temperature  $t = 40 \text{ }^\circ\text{C}$
- Material variant G1
- Operation on frequency inverter: No
- Explosion protection: No

Data specified for selection as per example Fig. 15

**Example:**

**Apply steps A – D to select the correct pump set.**

**A**

Plot Q and H for the two duty points (see data under “Given” in grey box).

Read propeller incidence angle.

**Result A:**

**Propeller incidence angle = 17°**

**B**

Plot operating range  $Q_{\min}$  and  $Q_{\max}$ .

Read required maximum motor power  $P_{\text{opera}}$ .

**Result B:**

**Motor power  $P_{\text{opera}} = 100 \text{ kW}$**

**C**

Take the respective power reserve for motor power  $P_{\text{opera}}$  (mains operation) from Table C and calculate

**Result C:**

**$P_{2 \text{ mot req.}} = 100 \text{ kW} \times 1.05 = 105 \text{ kW}$**

**D**

$P_{2 \text{ mot req.}}$  allows the motor size to be directly selected; ensure

$P_{2 \text{ mot}} \geq P_{2 \text{ mot req.}}$

**Result D:**

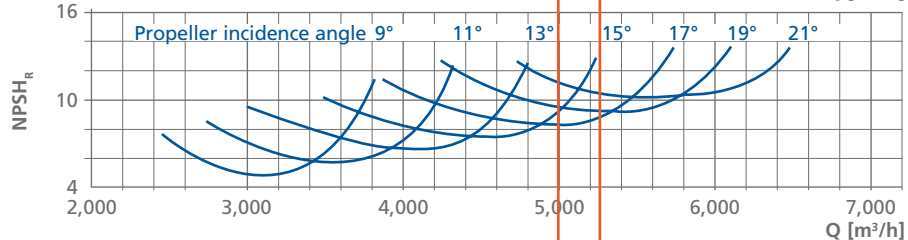
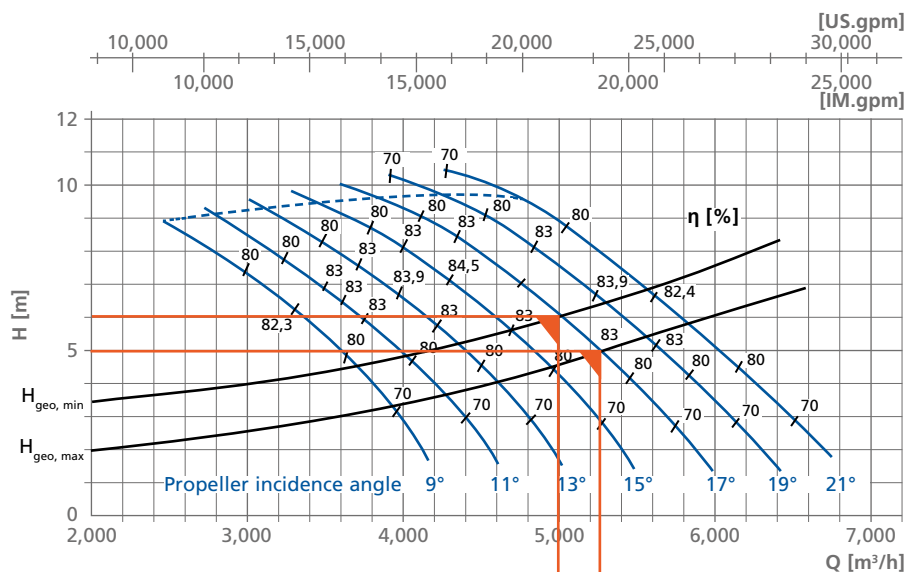
**6-pole, 120 kW (non-explosion-proof) motor (“U” model)**

**Amacan PA 4 800-540 / 120 6 UTG1**

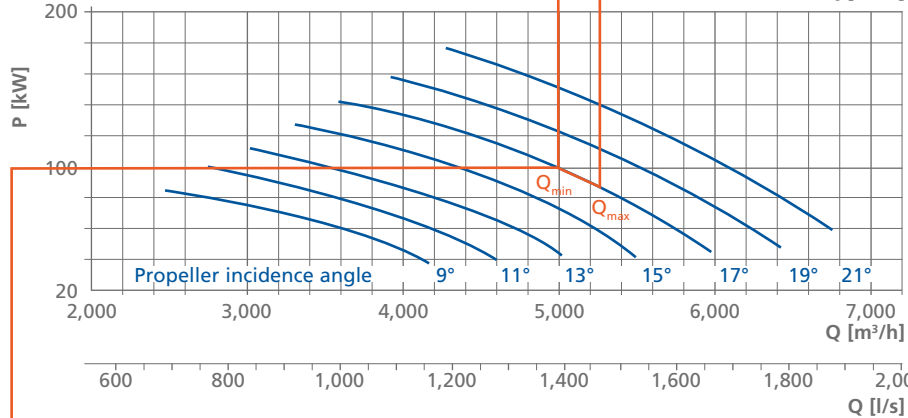
(for motor data see Motor Catalogue, reference No. 1580.505/...)



A



B



Recommended minimum reserves

C

Required pump power $P_{opera}$	Motor power reserve Mains operation	Motor power reserve Frequency inverter operation
< 30 kW	10 %	15 %
> 30 kW	5 %	10 %

5 % of 100 kW correspond to 105 kW.

An additional power reserve is required for operation on a frequency inverter.

D

Motor size selection

Amacan PA4 ... - 540/...	Rated power $P_2$ [kW]		Mass moment of inertia J [kgm <sup>2</sup> ]
	UTG	XTG	
800-540 / 80 6	80	80	3.25
800-540 / 100 6	100	100	3.38
800-540 / 120 6	115	115	3.52

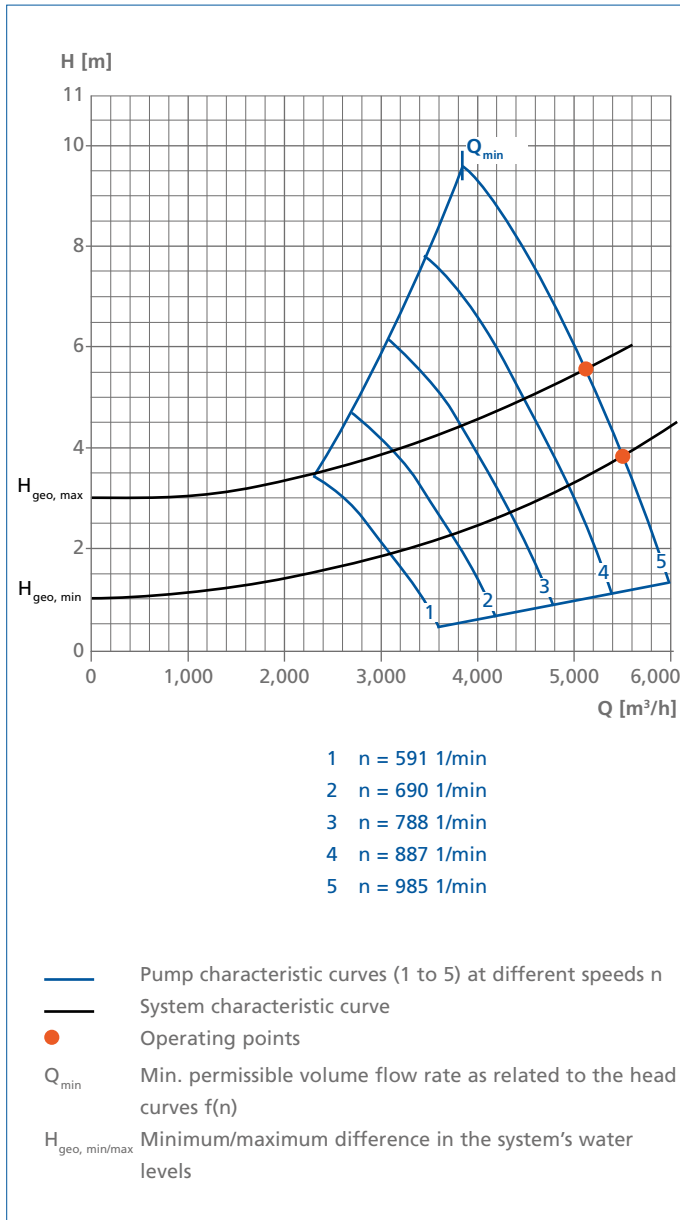


Fig. 16: Amacan P 800-540 A 4 with speed curves

## Pump drive with frequency inverter

Basically all pump motors can be used with frequency inverters. The characteristic curves of Amacan pumps installed in discharge tubes can be re-calculated using the affinity laws (Formula 5), as with all centrifugal pumps.

$$\frac{Q_2}{Q_1} = \frac{n_2}{n_1} \quad \frac{H_2}{H_1} = \left(\frac{n_2}{n_1}\right)^2 \quad \frac{P_2}{P_1} = \left(\frac{n_2}{n_1}\right)^3 \quad \text{Formula (5)}$$

Key:

- $n_1$  = Original speed [1/min]
- $n_2$  = New or proposed speed [1/min]
- $Q_{1,2}$  = Flow rate  $Q$  at  $n_{1,2}$  [ $m^3/h$ ]
- $H_{1,2}$  = Head  $H$  at  $n_{1,2}$  [m]
- $P_{1,2}$  = Power  $P$  at  $n_{1,2}$  [kW]

In principle, the aim of speed control is to optimally match the pump's operating point to the actual system requirements. As previously mentioned, three impeller types with different characteristics are available for this submersible pump type in discharge tube design. For each of these impeller types it is always important to check the control range. This includes determining the system curve(s) with  $H_{geo, min}$  and  $H_{geo, max}$ .

The following must also be checked:

- (a) The flow velocity in the discharge tube must be sufficient to transport fibres and solids which could be contained in the fluid handled ( $v_{mean} > 2$  m/s), and
- (b) The circumferential speed on the impeller's outside diameter (not less than 15 m/s). In variable speed operation it is vital that no operating point lies to the left of the permissible operating limit and that variable water levels are taken into account.

This means that **the limit speeds must be adjusted to comply with the actual water levels.**

If two or more pumps with a common discharge line are operated on frequency inverters, operating all pumps at the same speed is recommended. This is to avoid the pumps "pushing" each other into the low-flow operating range (with the associated negative effects on impeller, shaft seal and bearings). Checking the duty point and the resultant flow velocity also requires an evaluation of the fluid handled with regard to its dirt and fibre content. If the values recommended by the pump manufacturer are not complied with and problems arise, increasing the pump speed for a short time period may improve the situation. Every pumping station has its own specific set of operating conditions which should be taken into account (possible control range, proneness to pressure surges etc.).

# Pumping Station Design

## General

The structural requirements of a pumping station are largely determined by its purpose. Alongside purely structural and mechanical requirements, consideration must also be given to hydraulic aspects (fluid dynamics) in the planning and execution of the construction work. The first part of the hydraulic areas to be designed is the inlet upstream of the pumping station, followed by the intake chamber upstream of the pump(s), parts of which may require a special shape, and finally the discharge line or discharge system.

The pump manufacturers' aim is to specify in the product's technical literature the dimensions (e.g. geometry of the building) required for the installation of the centrifugal pumps. The reference values provided here are essential for the planning process, in particular for establishing the main dimensions of the pumping station. The successful planning of a pumping station is a complex task which encompasses questions on how to design the area between the intake and the pump(s) as well as the specification for the minimum spacing between the pumps or, in some cases, the dimensions to be observed for any necessary intake chambers. If the requirements regarding intake chamber dimensions, minimum water levels or the geometry of hydraulic areas within the pumping station are not met, i.e. deviations occur during the planning or construction phase, proper functioning of the entire station can no longer be guaranteed. In such a case, it is irrelevant whether these problems are caused by single or multiple deviations. The conditions for pump operation are not met due to these modifications or deviations and the problems arising as a result are reflected in either the operating behaviour or the performance of the centrifugal pump(s). Incorporating the pump manufacturer's hydraulic and mechanical design specifications in the pumping station's design process at an early stage can ensure that the required performance data is achieved and operating malfunctions avoided.

According to Prosser [6], the criteria for unsatisfactory pumping station design can be clearly defined and assessed. The following aspects of geometrical design can lead to poor sump performance:

1. Undersized control gates and valves
2. Abrupt changes in flow direction (e.g. sharp corners)
3. Submerged high-velocity flow areas (e.g. diffusers with an excessive angle of divergence)
4. Stepped sump floor
5. Weirs with no provision for dissipating the energy of the falling fluid
6. Blunt pillars, piers and guide vanes
7. Any design or mode of operation which leads to asymmetric distribution of the flow in the sump
8. Sump inlet above water level

Items 1, 2, 3, 6 and 7 may cause swirls at the pump's inlet. Air-entraining surface vortices and submerged vortices may form in extreme cases.

Items 4, 5 and 8 can lead to air intake in the fluid handled, and items 3, 4 and 5 may cause transient flow conditions within the sump.

The purpose of a pump sump is to provide stored volume and good conditions for the flow approaching the pump.

The following undesirable hydraulic conditions must be avoided:

- Jets (high-velocity flows) discharging into stagnant or slowly moving fluids (as these form large, transient eddies as downstream wakes)
- Areas of separated flow
- High-velocity flows ( $v > 2$  m/s)
- Transient flow
- Large surface waves
- Free-falling fluids

Smooth pump operation can be ensured if the pumping station design takes the above criteria into account. Manufacturers' literature such as type series booklets and software tools with CAD files provide a solid basis for designing and sizing pumping stations. (Example: KSB HELPS)

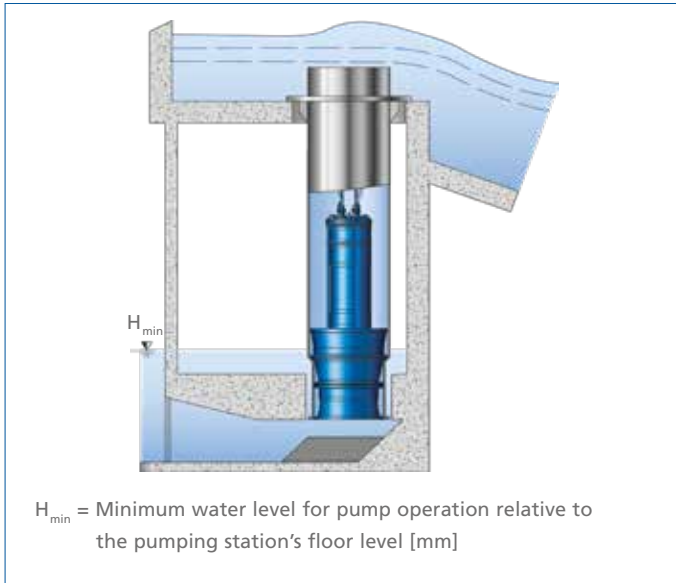


Fig. 17: Discharge tube design variant with free discharge

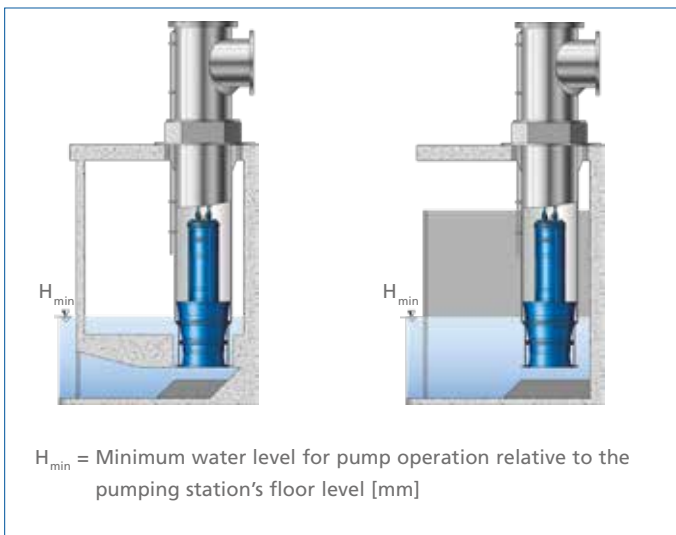


Fig. 18: Discharge tube design variants with above-floor discharge nozzle

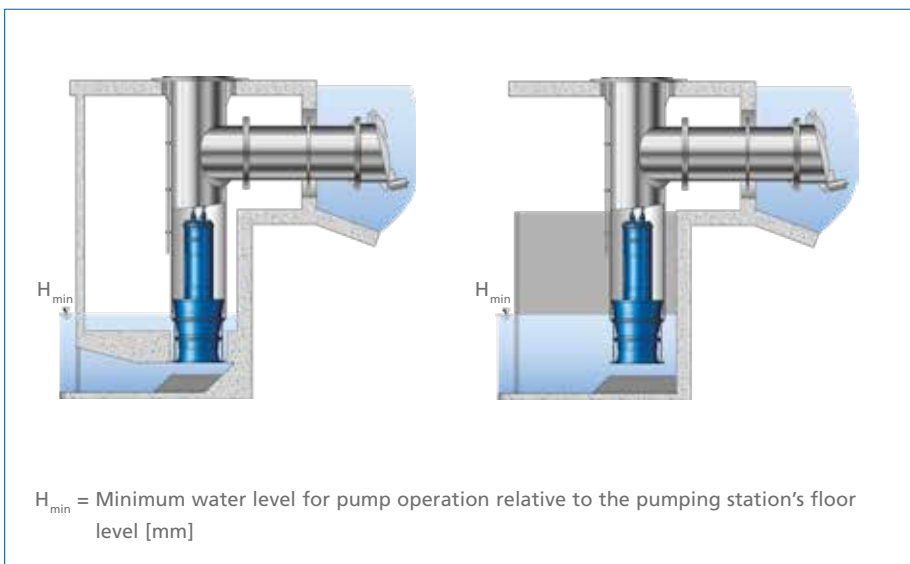


Fig. 19: Discharge tube design variants with underfloor discharge nozzle

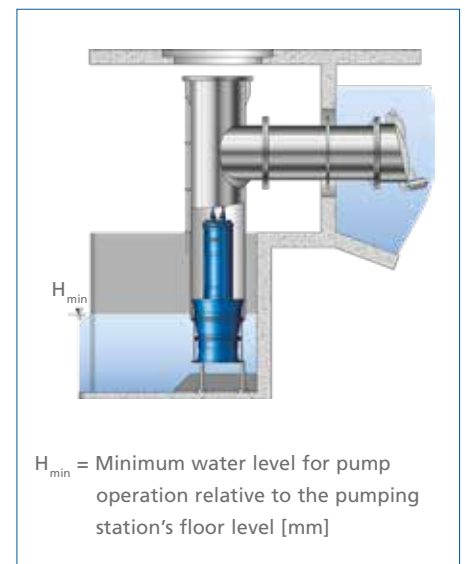


Fig. 20: Discharge tube design variant with underfloor discharge nozzle, traversable by vehicles

## Pump installation planning

After all hydraulic aspects regarding the distribution of the volume flow have been considered and the appropriate pump size chosen, the geometry of the intake chamber must be determined.

Thanks to a flexible discharge tube design, Amacan pumps offer a vast range of installation options, making optimum pumping station design possible. This gives system designers the flexibility to adapt the installation to any station design and system condition. Some installation options are briefly presented here.

The primary source of advice on planning should be the pump manufacturers' literature and internationally recognised standards [5].

Once the pumping station's dimensions have been roughly defined, detailed planning of the installation of the pump should be carried out with reference to the manufacturers' technical literature (e.g. type series booklet or selection software), where detailed information on the exact dimensions required for each particular pump size can be found. It is vital that these dimensions be observed to ensure problem-free pump operation.

Information on permissible maximum approach flow velocities and approach flow directions for the specific intake chamber geometries is also provided (see Section "Pump sump design" from page 33 onward).



The dimensions essential for the intake chamber are its width and length as well as the distances between rear wall / floor and pump (see Fig. 21). The required minimum water level has to be established on the basis of the pump's volume flow rate in order to ensure smooth pump operation without air-entraining surface vortices.

When determining the appropriate intake chamber geometry, the pumping station designer must also consider any operating conditions which will occur when the pumping station is being operated with a reduced number of pumps. This may result in substantially different intake chamber flow conditions in terms of approach flow velocity and approach flow direction (see Section "Pump sump design" from page 33 onward).

Whether the pumping station is equipped with one or several pumps has no influence on the intake chamber dimensions or the discharge tube.

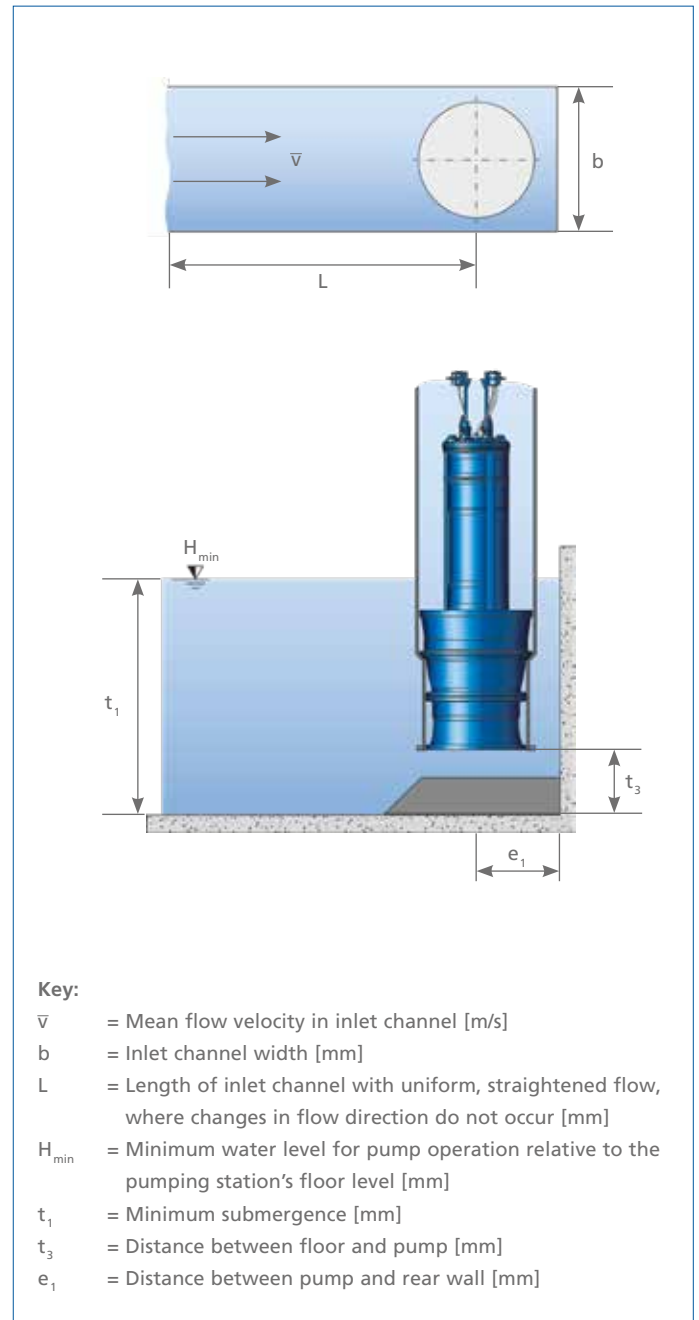


Fig. 21: Important intake chamber dimensions (see the type series booklet or selection software for the actual dimensions)

### Open intake chambers

If the water level in the pump sump is sufficiently high and the flow approaches the chamber directly from the front, with a tolerance of 10 degrees maximum, then this form of intake chamber design is the most cost-efficient variant.

The approach flow velocity must not exceed 1 m/s within the intake chamber. Flow approaching the pump at an angle of more than  $\pm 10^\circ$  must be ruled out to avoid flow separation and vortex formation. This also applies in the event of altered operating conditions.

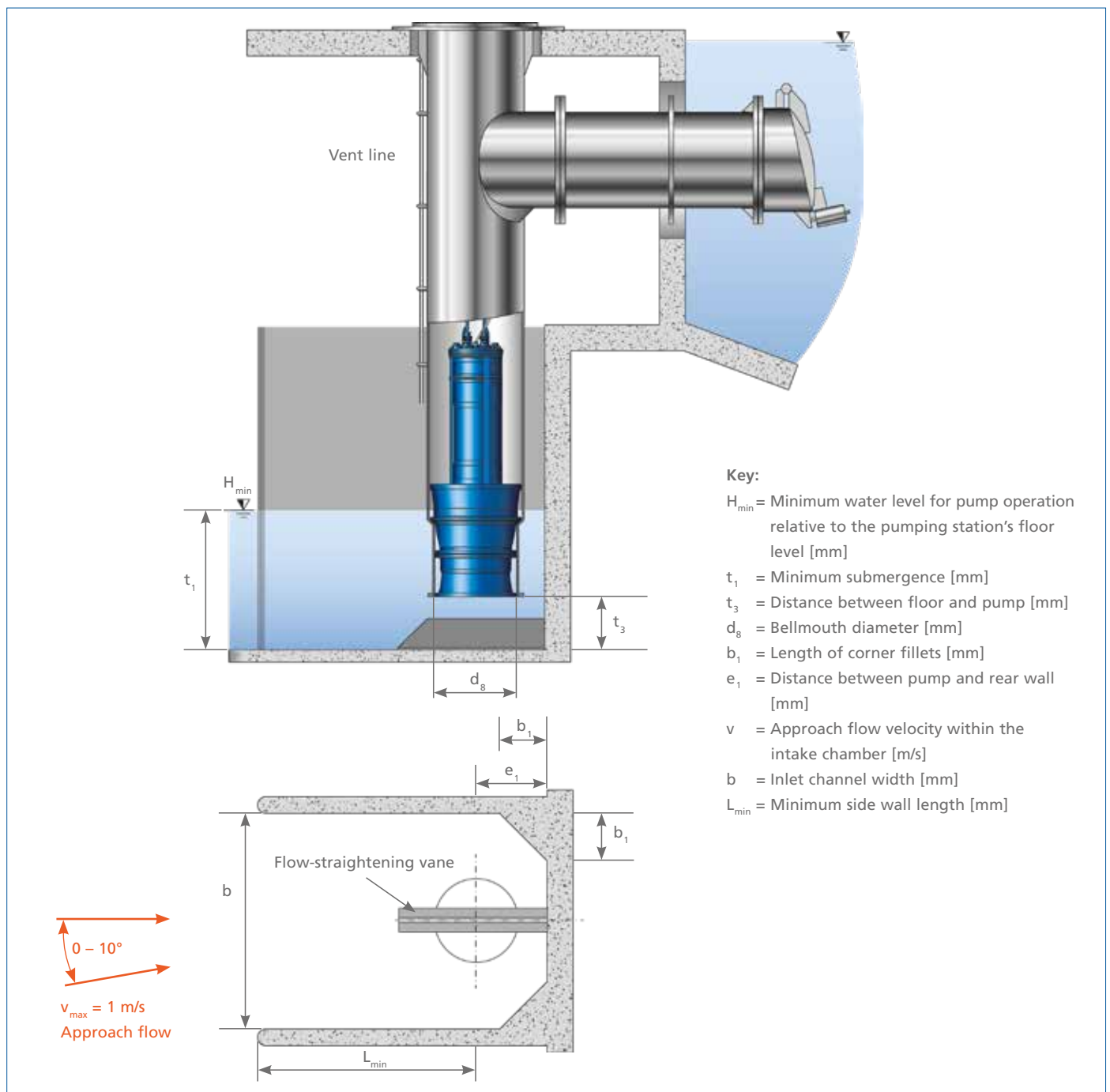


Fig. 22: Open intake chamber (see the type series booklet or selection software for the actual dimensions)

### Open intake chambers with suction umbrella

If a check of the minimum water level in the pump sump establishes that this is insufficient, another chamber variant without corner fillets in combination with a suction umbrella fitted at the discharge tube's inlet may provide sufficient submergence to prevent air-entraining vortices. This allows the pump to operate at a lower suction-side minimum water level  $t_1$  with the same pump size and the same operating point.

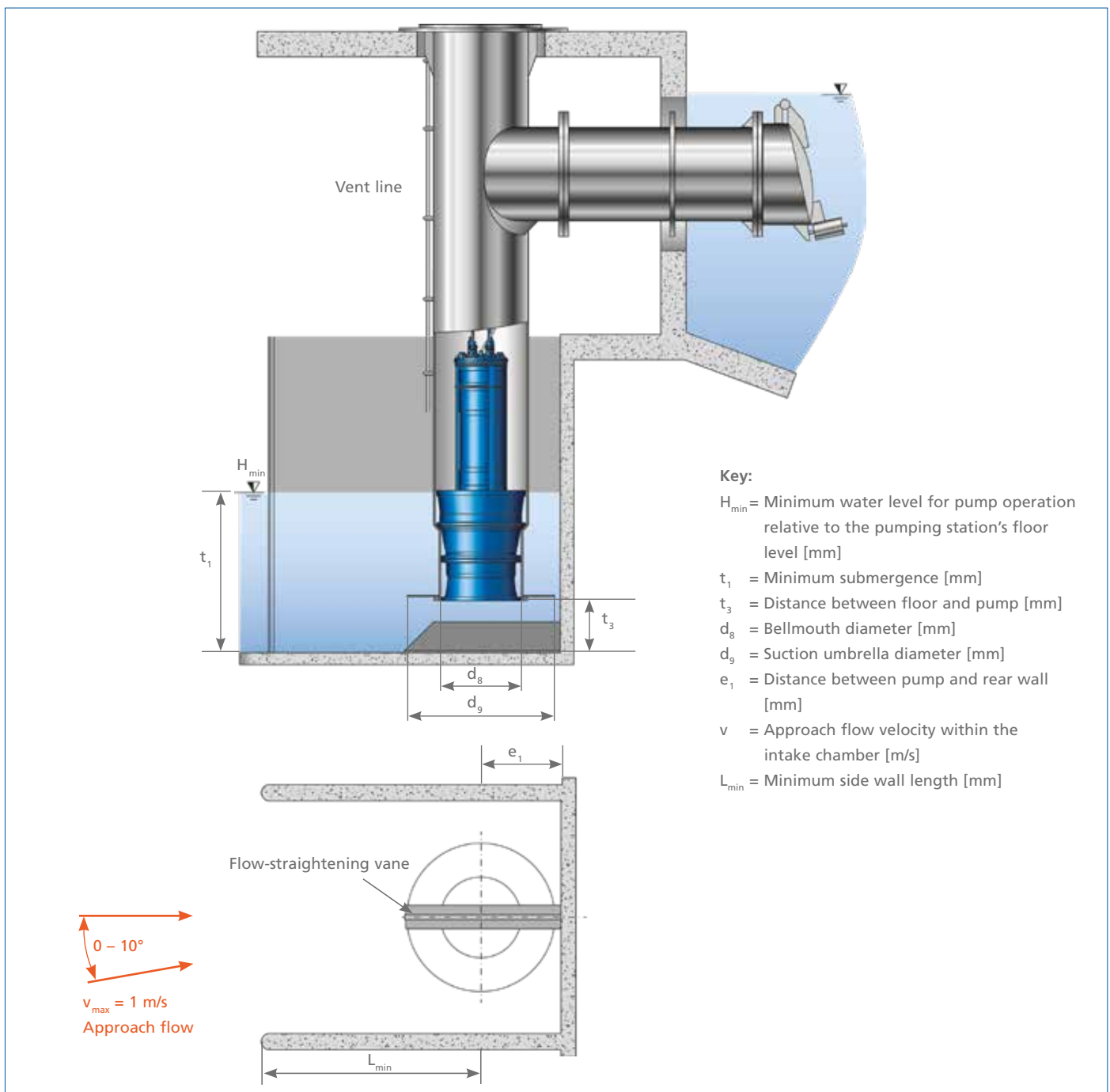


Fig. 23: Open intake chamber with suction umbrella (see the type series booklet or selection software for the actual dimensions)

### Covered intake chambers

A special type of chamber is the covered intake chamber. It allows the lowest minimum water levels without the occurrence of air-entraining surface vortices and can accommodate flows approaching at an angle of 0 to 90 degrees at 1 m/s max.

However, this variant involves higher construction costs than the chamber types previously described. This type of chamber has more than proved its worth under unfavourable approach flow conditions and low water levels.

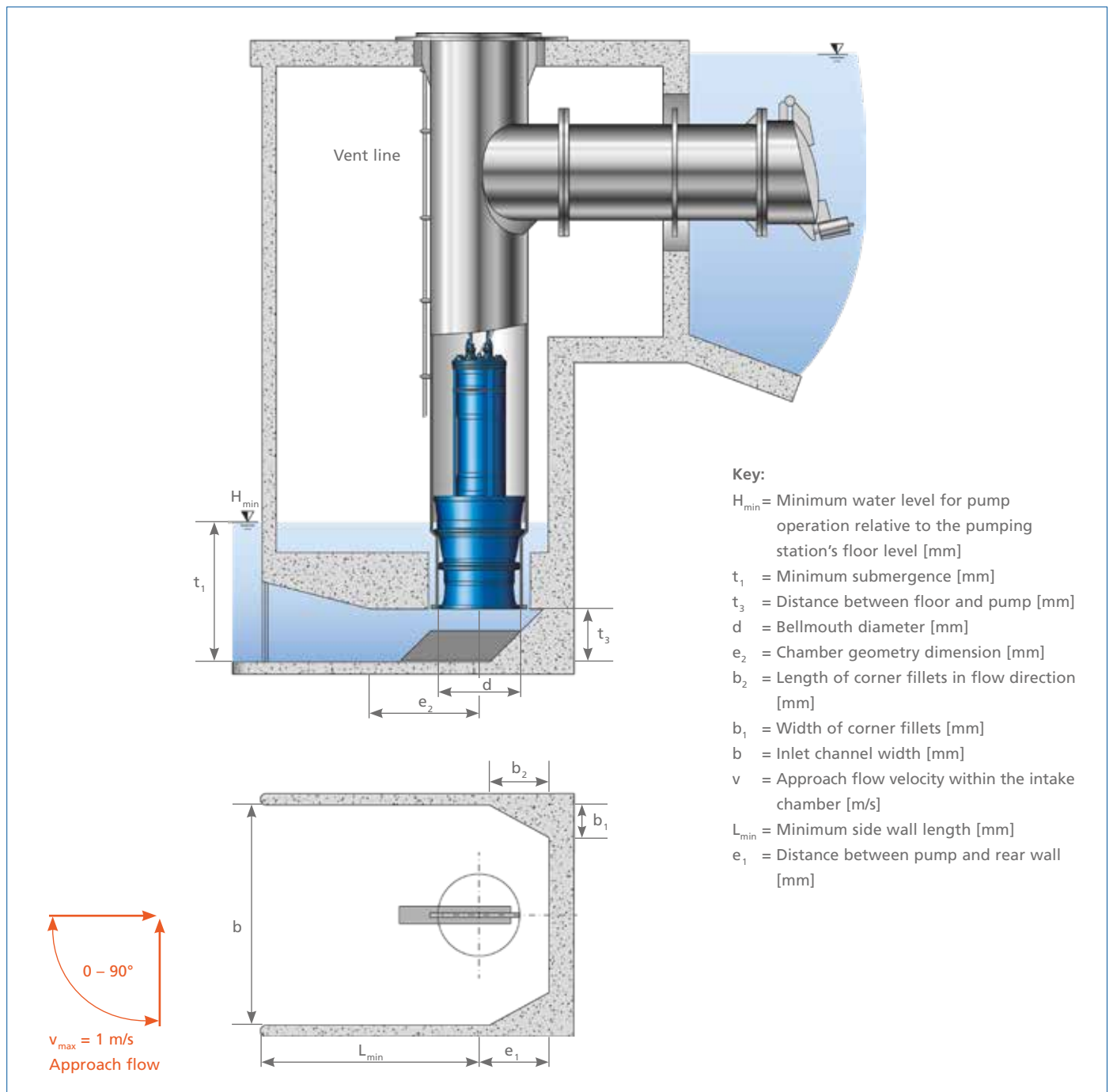


Fig. 24: Covered intake chamber (see the type series booklet or selection software for the actual dimensions)



### Details of intake chamber design

Unlike pumps from the Amacan K series, Amacan P and Amacan S pumps have to be installed in intake chambers. An important criterion for the chamber walls is a minimum height of 150 mm above the maximum water level in the pump sump (Fig. 25).

This is to ensure that the shape of the chamber does not favour vortex formation even under maximum water level conditions.

The walls in the intake section of the chamber should always be rounded to rule out the possibility of additional vortices forming if the flow to the chamber is skewed. This requirement is vital for both single-pump intake chambers with approach flows from the side and multiple-pump chambers with central inlet flows (Fig. 26).

All intake chamber designs for Amacan P and Amacan S pumps should include a flow-straightening vane under the pump inlet to prevent the occurrence of a submerged vortex which can inhibit pump performance, among other things. This vane can either be a concrete or steel construction. The precise vane dimensions are stipulated in the type series booklet or selection software.

The costs for concrete formwork in the chambers can be reduced by using straight contours. However, concrete fillings are required in areas where dead zones could occur (this only applies to open intake chambers without suction umbrella). The intake chamber corners must then be filled with concrete up to a minimum height of 150 mm above the maximum water level. Depending on the pumping station concept, the designers may allow for the possibility of shutting off and draining individual intake chambers if required. For this purpose, mounting devices for stop logs can be integrated into the chamber wall or the chamber can be shut off by appropriate flood gates.

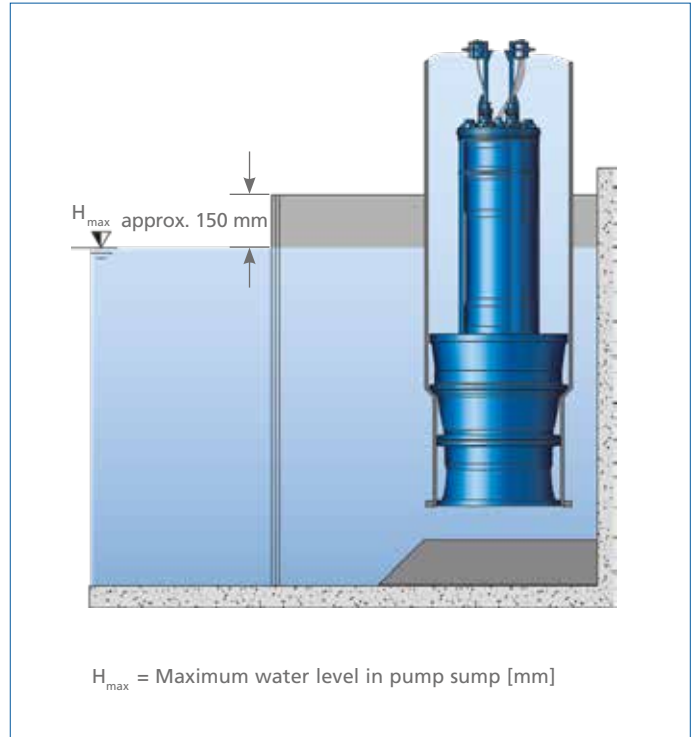


Fig. 25: Chamber wall height

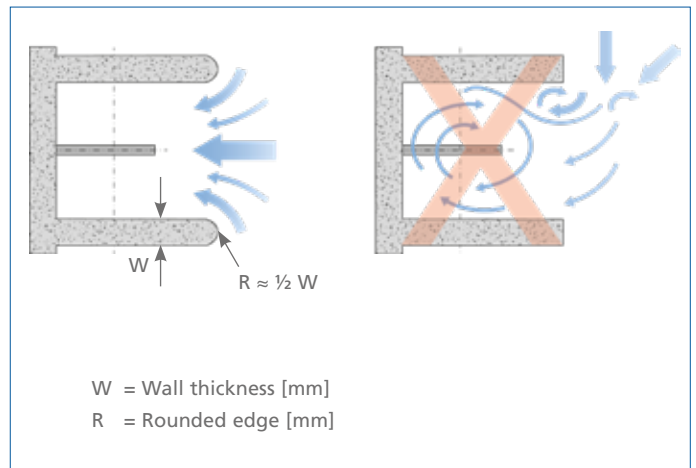


Fig. 26: Chamber inlet design

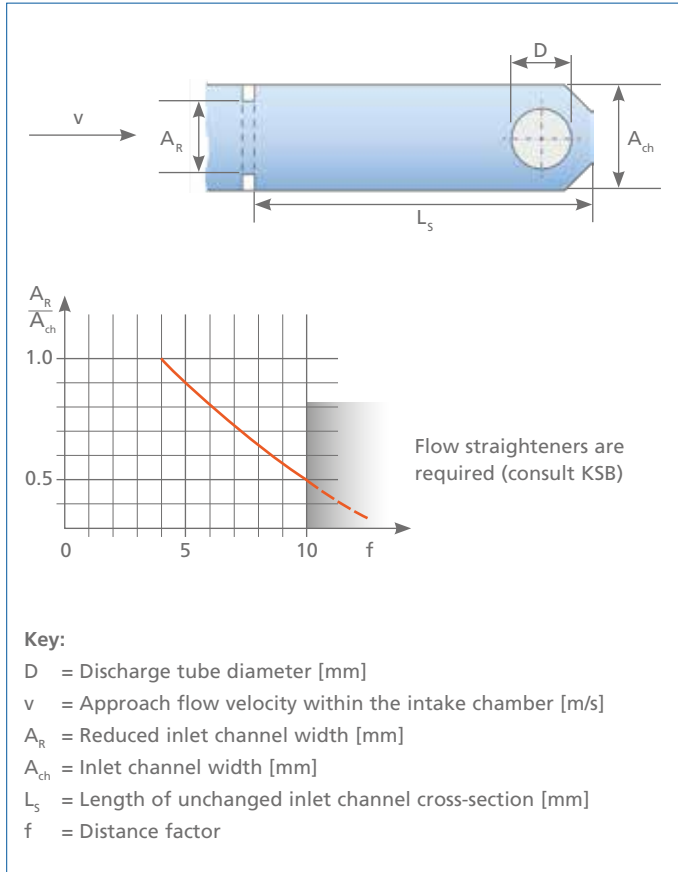


Fig. 27: Influence of cross-sectional constriction

If these mounting devices constrict the free flow cross-section, the distance between the pump and this point of flow disturbance must be checked and increased where necessary (Fig. 27).

$$L_s = D \cdot f \quad [\text{mm}]$$

Formula (6)

**Key:**

- L<sub>s</sub> = Length of unchanged inlet channel cross-section downstream of flow disturbance [mm]
- D = Discharge tube diameter [mm]
- f = Distance factor (see Fig. 27)

The intake chamber surfaces as well as the wall around the pump sump should have rough concrete surfaces. If the areas in contact with the fluid handled are too smooth or even provided with a paint coat, this may lead to the reduction of the wall shearing stress – and thus increase the risk of vortex formation (submerged vortices, and possibly surface vortices).

The roughness of surfaces in contact with the fluid should range from 1 to 3 mm.

In some circumstances, it might be necessary to adapt the intake structure to the specific requirements of a project. It is conceivable, for instance, that an intake elbow might be employed in place of a chamber (see Fig. 28). These elbows have properties comparable with those of covered intake chambers, i.e. they straighten the flow and ensure an even distribution of flow velocity across the pump's inlet cross-section. As the sizing of such special options must comply with the project data, it should only be undertaken after consultation with the responsible KSB departments.

If special solutions are unavoidable for certain projects, these should be examined with appropriate model tests and/or CFD (Computational Fluid Dynamics) simulations (see Fig. 29). Please note that prior assurance of the trouble-free functioning of the system under these specific project conditions must be obtained for such non-standard solutions (cf. Section “The necessity of model testing” from page 39 onward and “The significance of CFD simulation”, from page 43 onward).

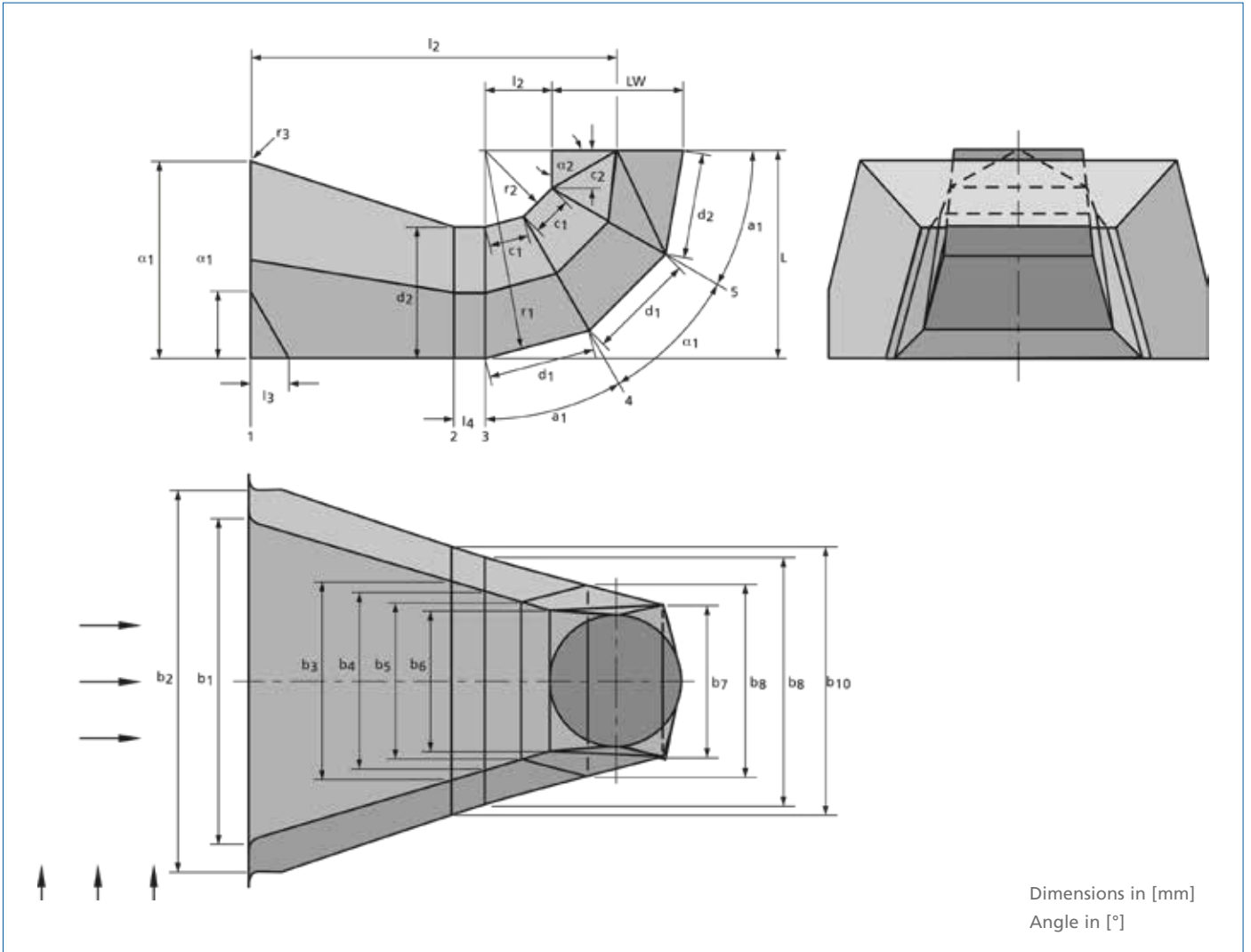


Fig. 28: Variant of a mitred elbow

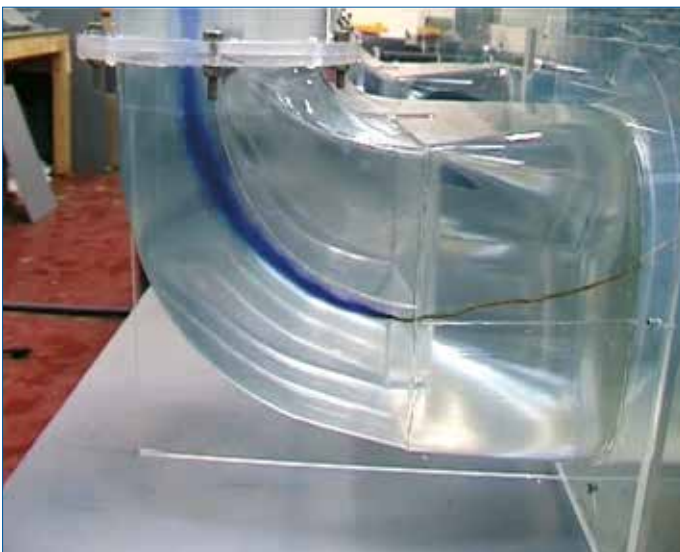


Fig. 29: Model test set-up with two elbows

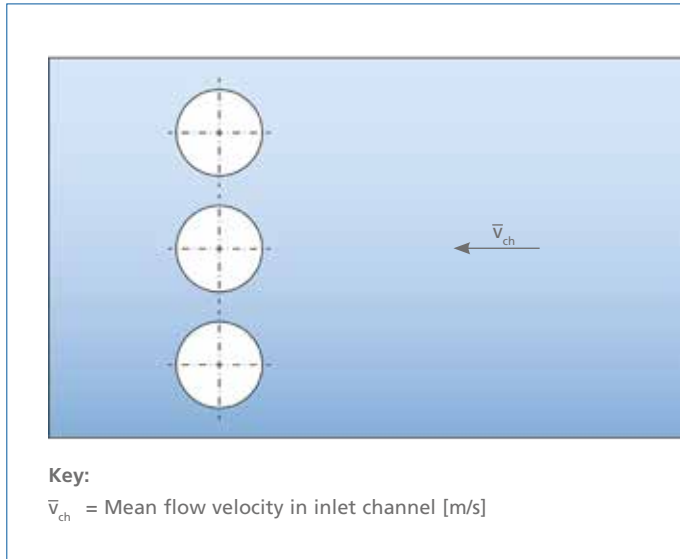


Fig. 30: Scenario, Variant 1

## Example of pumping station planning

### Variant 1

#### Scenario:

The pumping station comprising three pumps is to transport fluid from a channel. The inflow to the pumps is described as being even across the channel width.

#### Problem:

As the distance between the discharge tubes and the rear wall is too big, vortices may develop behind the discharge tubes as a result of separated flow. The absence of intake chambers creates the risk of the pumps influencing each other and of undefined approach flow in the case of single-pump operation.

#### Solution:

Each pump is to be provided with an intake chamber sized to match the respective pump (see the type series booklet or selection software). This ensures defined approach flow conditions and rules out any possibility of the pumps influencing each other during pumping.

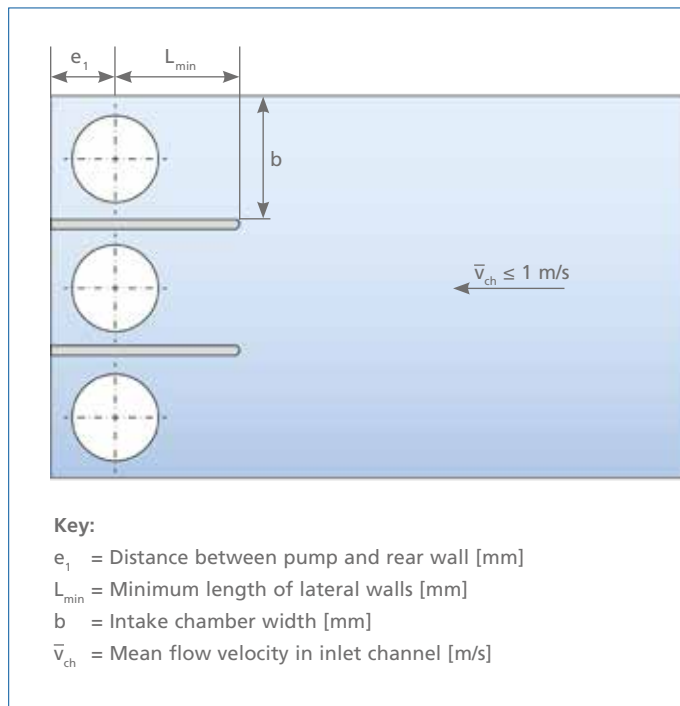


Fig. 31: Solution, Variant 1



## Variant 2

### Scenario:

The pumping station comprising three pumps is to transport fluid from a pump sump which is fed with fluid from an off-centre, front pipe / channel. In addition, the pumps are installed asymmetrically with regard to the inflow; intake chambers have not been provided.

### Problem:

The off-centre inflow into the pump sump causes an anti-clockwise rotation of the fluid in the pump sump. The velocity in the inlet channel / pipe determines the intensity of this rotation and, as a consequence, that of the uneven approach flow.

### Solution:

Each pump is to be provided with a complete intake chamber sized to match the respective pump (see the type series booklet or selection software). This will rule out any possibility of the pumps influencing each other during pumping. A curtain wall with an opening towards the floor is to be installed to ensure a uniform approach flow. This will help prevent the fluid from rotating.

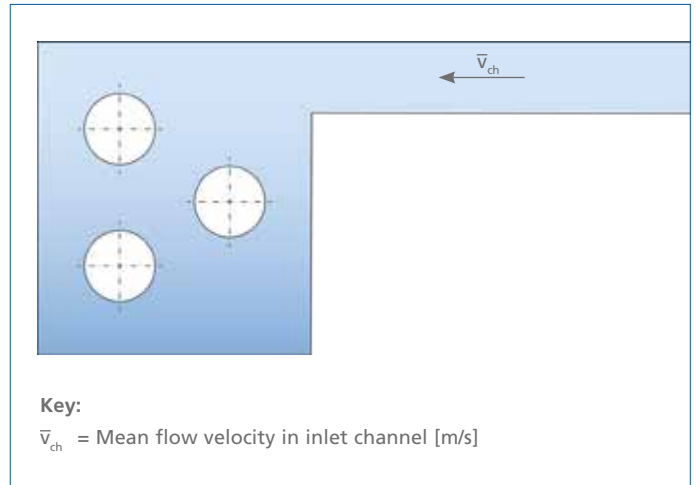


Fig. 32: Scenario, Variant 2

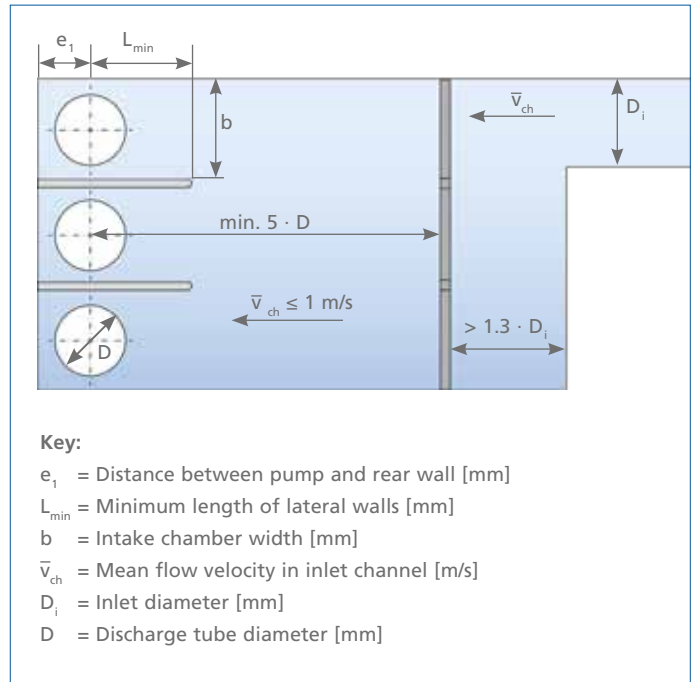


Fig. 33: Solution, Variant 2

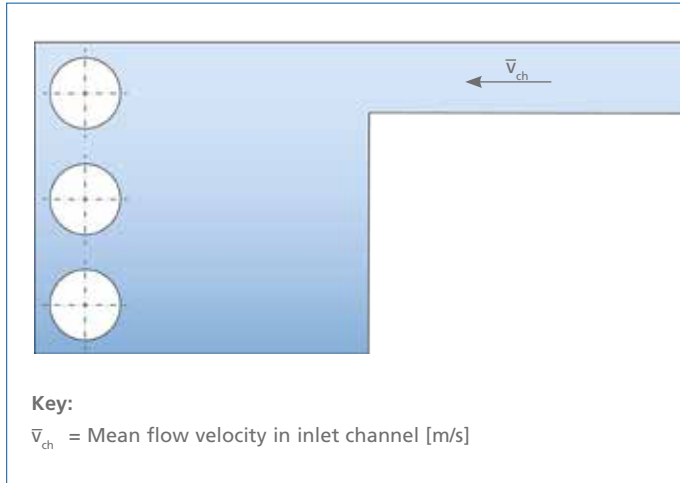


Fig. 34: Scenario, Variant 3

### VARIANT 3

#### Scenario:

The pumping station comprising three pumps is to transport fluid from a pump sump which is fed with fluid from an off-centre, front pipe / channel. In addition, the pumps are installed asymmetrically with regard to the inflow; intake chambers have not been provided.

#### Problem:

The off-centre inflow into the pump sump causes an anti-clockwise rotation of the fluid in the pump sump. The velocity in the inlet channel / pipe determines the intensity of this rotation and, as a consequence, that of the uneven approach flow.

#### Solution:

Each pump is to be provided with a complete intake chamber sized to match the respective pump (see the type series booklet or selection software). This will rule out any possibility of the pumps influencing each other during pumping. A curtain wall with an opening towards the floor is to be installed to ensure a uniform approach flow. This will help prevent the fluid from rotating.

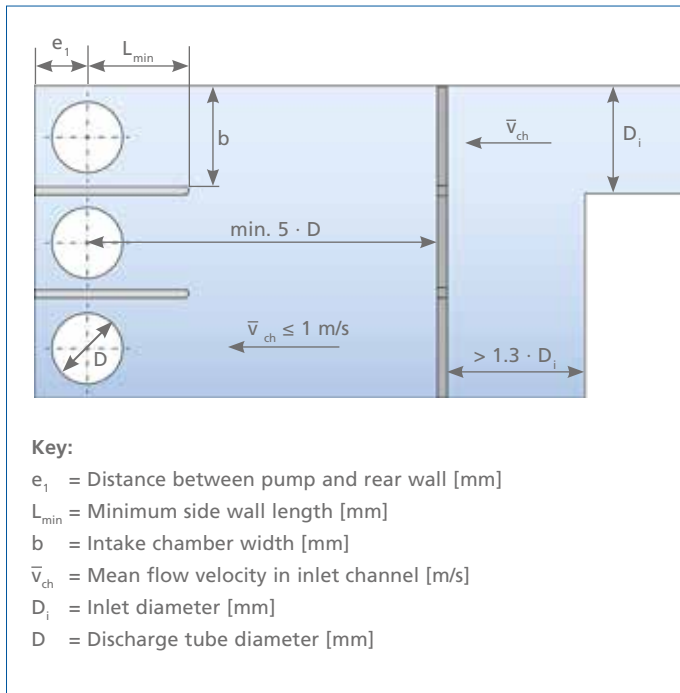


Fig. 35: Solution, Variant 3

### Variant 4.1

#### Scenario:

The pumping station comprising three pumps is to transport fluid from a channel. The flow from the channel approaches the pumps centrally.

#### Problem:

The fluid approach from the channel to the sump is symmetrical with regard to the installation positions of the pumps. However, vortices may form as a result of flow separation, leading ultimately to the risk of uneven velocity distribution among the pumps.

The absence of any intake chambers means an undefined approach flow, with the accompanying risk of the pumps influencing each other.

#### Solution:

Each pump is to be provided with a complete intake chamber sized to match the respective pump (see the type series booklet or selection software). The intake chambers are installed facing the inlet in the opposite sump wall. A curtain wall with openings (openings in the wall and near the floor) should be installed across the entire width of the pump sump upstream of the intake chambers. This prevents the pumps from influencing each other during pumping and ensures an even approach flow.

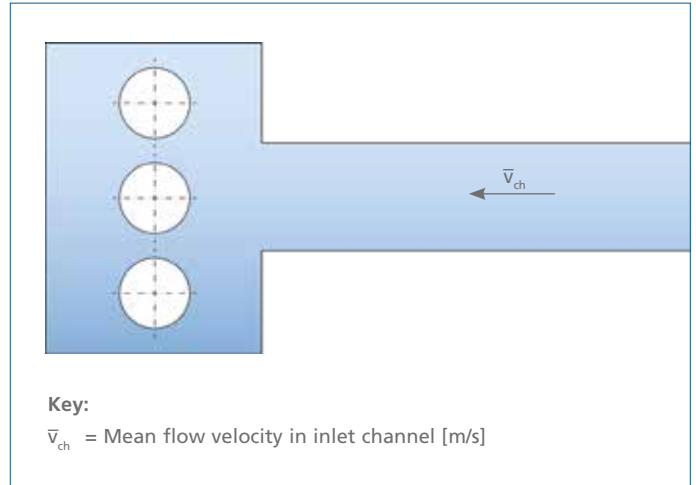


Fig. 36: Scenario, Variant 4.1

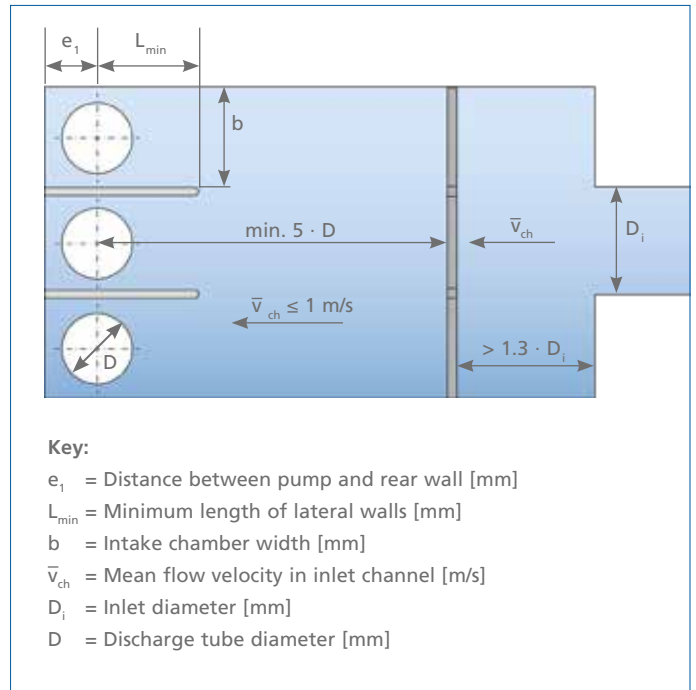


Fig. 37: Solution, Variant 4.1

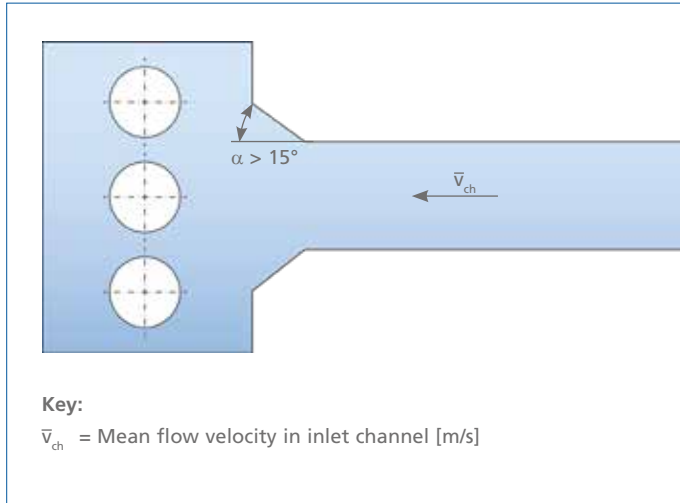


Fig. 38: Scenario, Variant 4.2

**Variant 4.2****Scenario:**

Three pumps are installed to pump fluid from one pump sump. The flow approaches the sump in the centre. The pumps are installed perpendicular to the flow direction and do not have intake chambers. To reduce the velocity in the sump the inlet channel has been widened. The distance between the pumps and the rear wall is extremely large.

**Problem:**

Due to the fluid approach from the channel to the sump, vortices may form as a result of flow separation, leading ultimately to the risk of uneven velocity distribution upstream of the pumps. The angle of divergence is too wide and causes problems with vortices and velocity distribution as mentioned above. As intake chambers are not available, there is the risk of the pumps influencing each other and of undefined approach flow.

**Solution:**

Each pump is to be provided with a complete intake chamber sized to match the respective pump (see the type series booklet or selection software). The intake chambers are installed facing the inlet in the opposite sump wall. A curtain wall with openings near the floor should be installed across the entire width of the pump sump upstream of the intake chambers. This prevents the pumps from influencing each other during pumping and ensures an even approach flow.

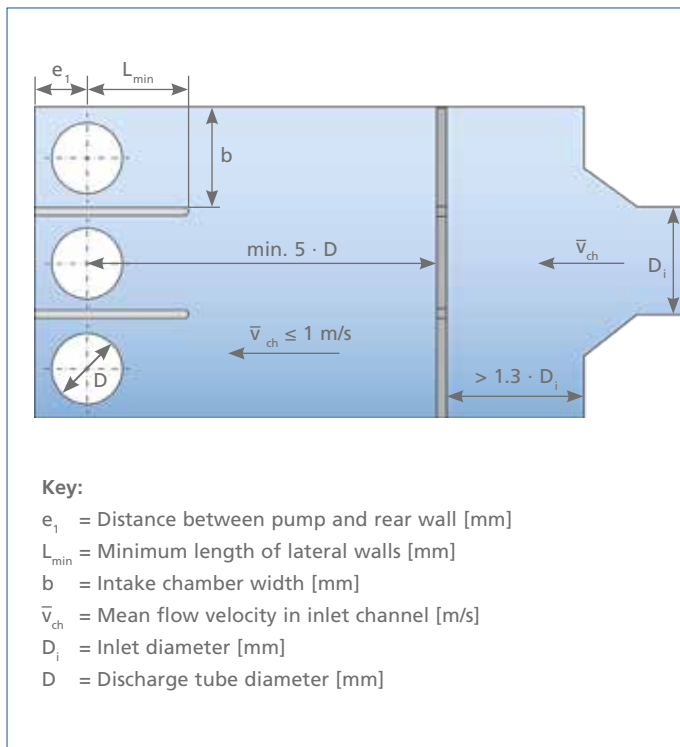


Fig. 39: Solution, Variant 4.2

## Variant 5

### Scenario:

The pumping station comprising three pumps is to transport fluid from a channel. The pumps do not have intake chambers and the fluid flow approaches the line of pumps perpendicularly.

### Problem:

The pumps are completely exposed to the cross flow. Wake turbulence forms downstream of the discharge tubes and the pumps influence each other during pumping.

### Solution:

Each pump is provided with a covered intake chamber. As a result, perpendicular flows of up to a maximum of 1 m/s can be handled without any problems. The intake chambers are sized to match the actual pump size (see type series booklet or selection software). The front edges of the intake chambers should be in line with the channel wall to avoid additional flow constrictions and marked differences in flow velocities in the channel.

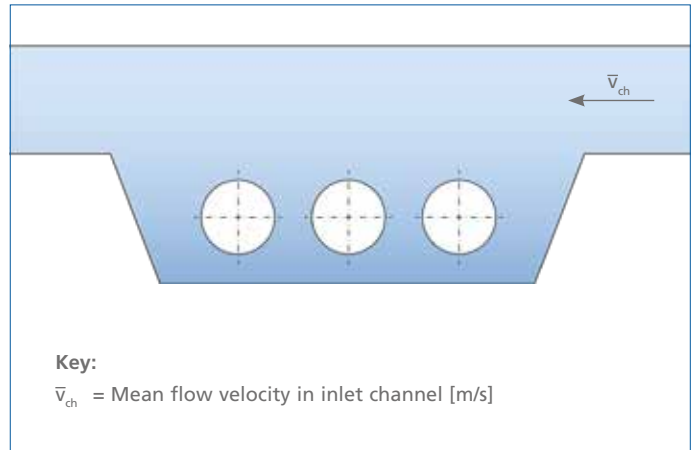


Fig. 40: Scenario, Variant 5

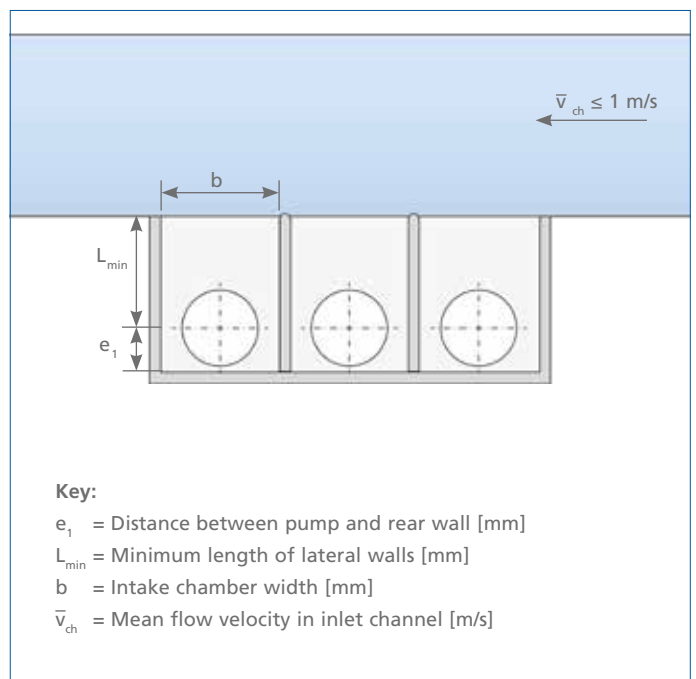


Fig. 41: Solution, Variant 5

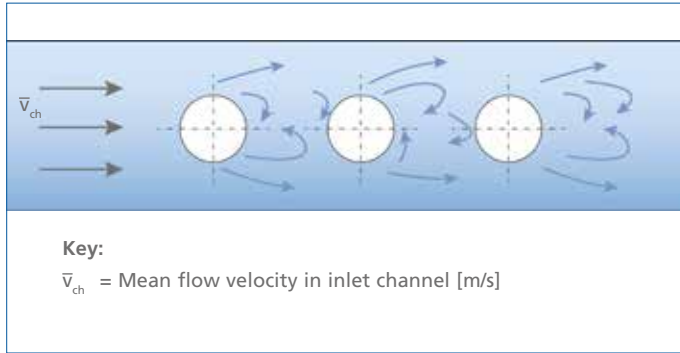


Fig. 42: Scenario, Variant 6

**Variant 6****Scenario:**

The pumping station comprising three pumps is to transport fluid from a channel. The pumps are installed in line with the flow. The pumps are not separated from each other through chambers or guide walls.

**Problem:**

The approach flow from the channel creates the risk of vortices caused by flow separation and uneven velocity distribution up- and downstream of the pumps. The absence of any intake chambers means an undefined approach flow, with the accompanying risk of the pumps influencing each other.

**Solution:**

Each pump is to be provided with a covered intake chamber sized to match the respective pump (see the type series booklet or selection software). This will rule out any possibility of the pumps influencing each other, while the approach flow conditions are exactly defined. The front edges of the intake chambers should be in line with the channel wall to avoid additional flow constrictions and marked differences in flow velocities in the channel.

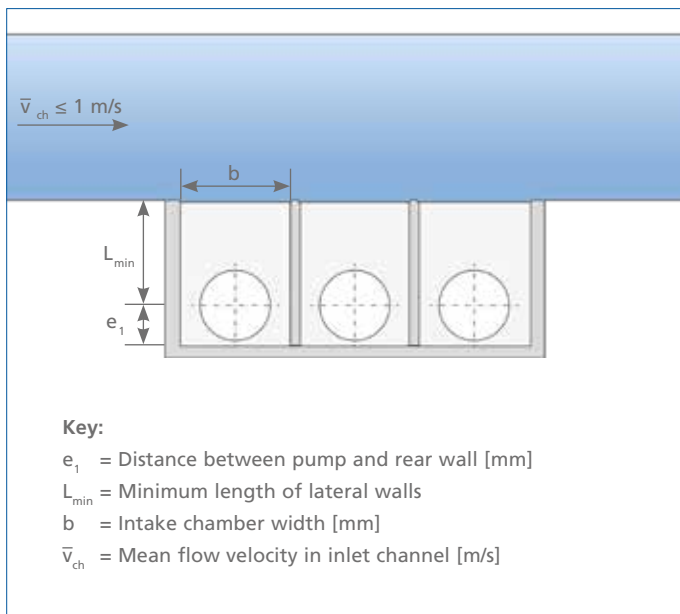


Fig. 43: Solution, Variant 6



## Variant 7

### Scenario:

The pumping station comprising three pumps is to transport fluid from a channel. The approach flow to the pumps is described as being even across the entire channel width. The pumps are separated from each other by profiled rear walls in the sump.

### Problem:

The absence of any intake chambers means an undefined approach flow, with the accompanying risk of the pumps influencing each other. This leads to unpredictable flow conditions especially when operating the system with a reduced number of pumps.

### Solution:

Each pump is to be provided with a complete intake chamber sized to match the respective pump (see the type series booklet or selection software). This will rule out any possibility of the pumps influencing each other.

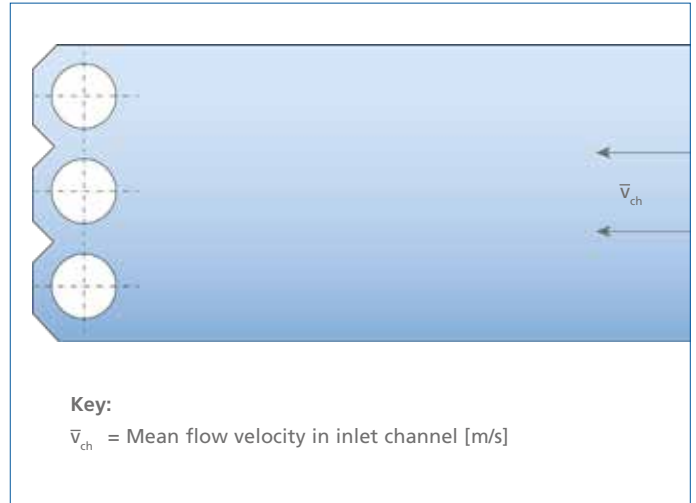


Fig. 44: Scenario, Variant 7

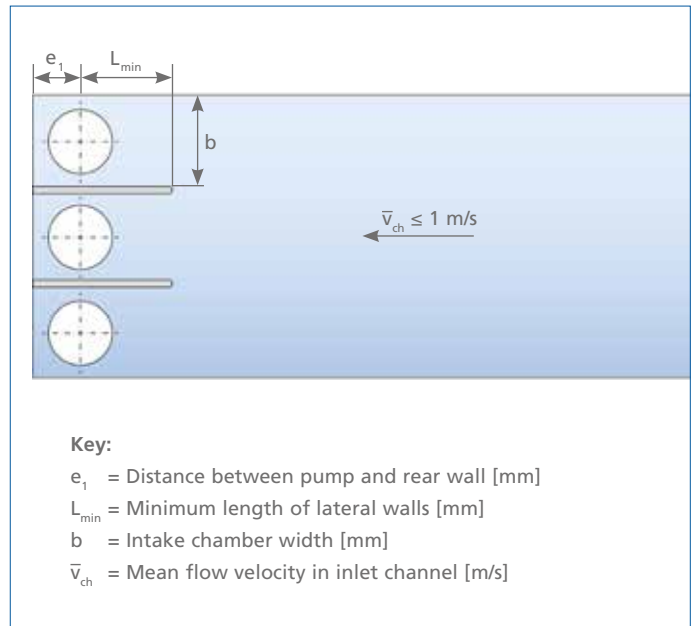


Fig. 45: Solution, Variant 7

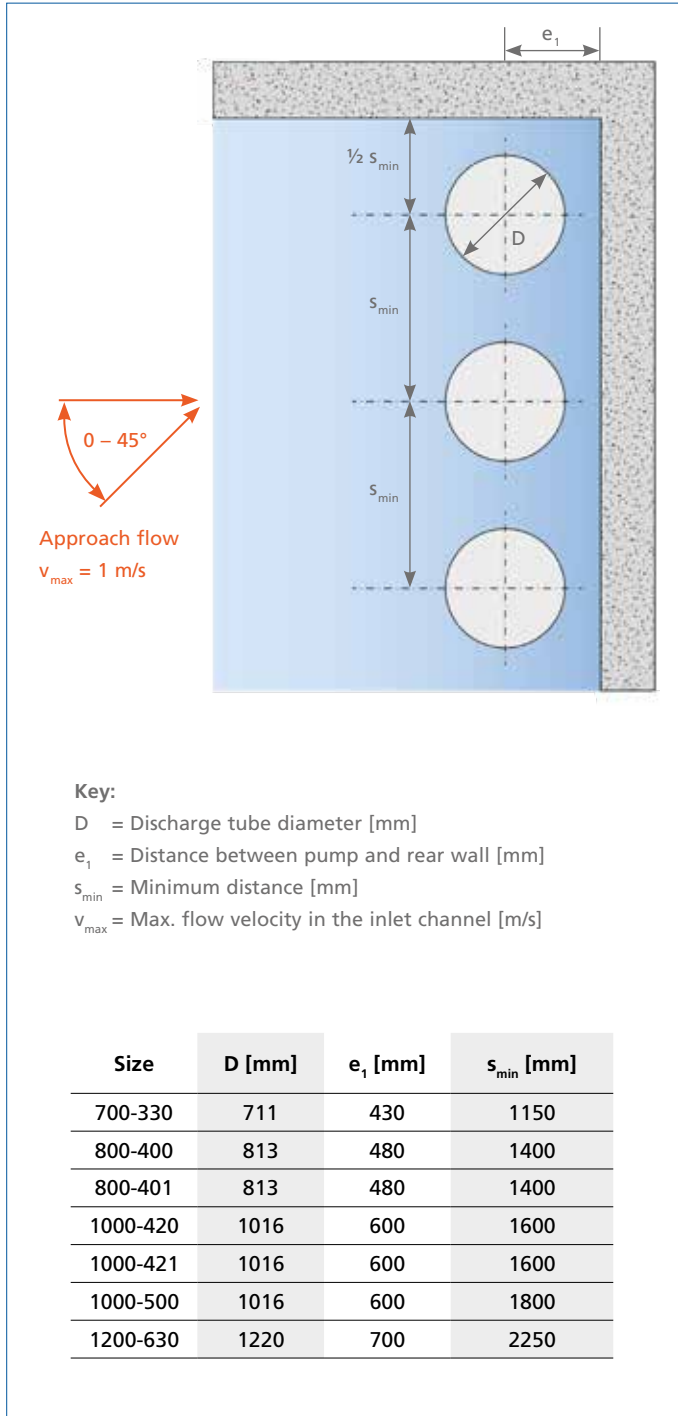


Fig. 46: Minimum dimensions, Amacan K

## Amacan K: A special case

Thanks to its channel impeller, this pump type is relatively straightforward with regard to the pumping station design. Amacan K pumps can be installed into the discharge tubes with no need for any special intake chambers or separating walls between the pumps. To rule out any possibility of the pumps influencing each other, it is however important to observe the required installation distances: the lateral distance between the pump and the accommodating building as well as the inter-pump spacing, and the distance  $e_1$  between the rear wall and the pumps' centreline. Fig. 46 offers a basic guidance for a pump installation concept.

The following conditions should be assumed as reference values for a preliminary concept:

- Observing the rear wall distance  $e_1 \approx 0.6 \cdot D$  is crucial.
- The required minimum water level  $t_1$  – as is also the case with the other submersible pumps installed in discharge tubes – is a function of the volume flow rate  $Q$  and documented in the type series booklet.
- The lateral distance  $S_{min}$  should also be observed (see type series booklet and the excerpt of data from it in Fig. 46).
- Flow straighteners as used for Amacan P or Amacan S are not required.

Where approach angles differ and approach flow velocities are higher than 1 m/s, it is necessary to take measures suited to deal with that specific intake situation (see Section "Pump sump design" from page 33 onward).

## Pump sump design

The fluid storage space or the pump sump connects the pumping station intake with the submersible pump in the discharge tube. There are as many variations in the design of this part of the intake structure as there are pump installation options. The following section can only examine a small number of examples; the dimensions in the drawings refer to these cases only. If project or modification conditions deviate from the examples described here, we recommend consulting KSB.

One feature of an optimum pump sump design is that there are no major steps or slopes with an inclination of more than 8 degrees on the sump floor. A distance of at least 4 to 5 D (D = discharge tube diameter) should be maintained from the last point of disturbance or floor alteration to the pump centreline. Higher steps (> 100 mm) should be avoided at all costs in order to prevent submerged areas of flow separation and floor vortices.

When the flow enters the pumping station structure from a channel, either a diffuser-type enlargement (number of pumps  $n$  + chamber width  $\cdot n + (n - 1) \cdot$  wall thickness) or a so-called curtain wall is required. Which of these measures is appropriate for the project in hand must be individually decided upon.

While some sources give details of installations where submersible pumps in discharge tube design do not have their own intake chambers, KSB, in contrast, believes that each pump should be provided with its own, fully shaped intake chamber (see Sections "Open intake chambers" from page 18 onward to "Covered intake chambers" from page 20 onward) in order to rule out any possibility of the pumps influencing each other. Actual inflow conditions are difficult to predict, as vortices may form even in the case of low pump flow rates as a result of various influences in the intake structure or the pumping station's mode of operation, with the accompanying negative effects on the pumps.

According to KSB, approach flow velocities of no higher than 1 m/s are permitted for the intake chamber geometries specified in the type series booklets. Therefore, with a view to reducing the intake building structure, it is necessary that the conditions around the pump are optimally designed to avoid problems.

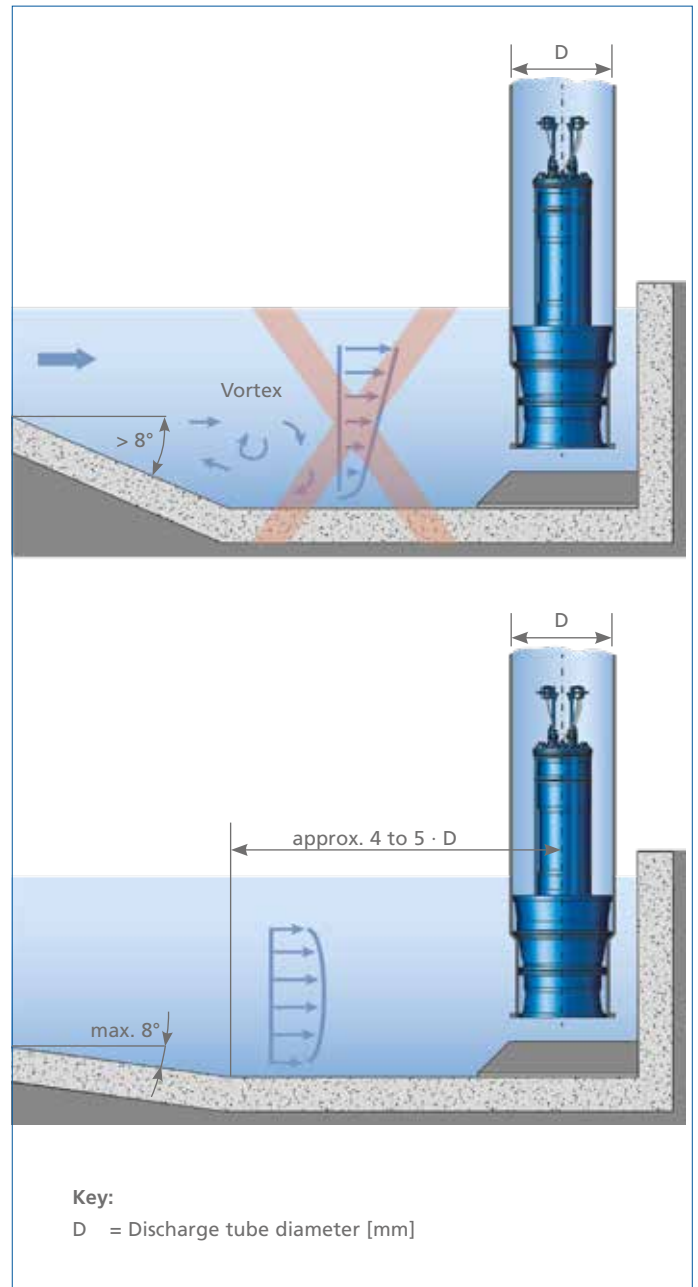


Fig. 47: Shape of sump floor

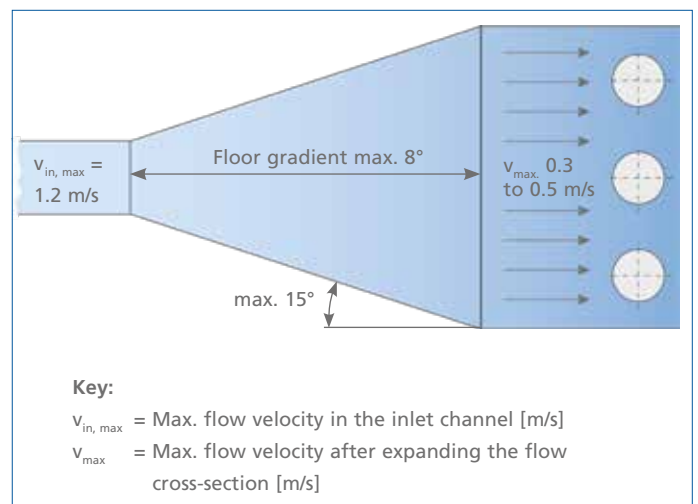


Fig. 48: Maximum permissible divergence angle for flow cross-section and permissible velocities (see [5] and [12])

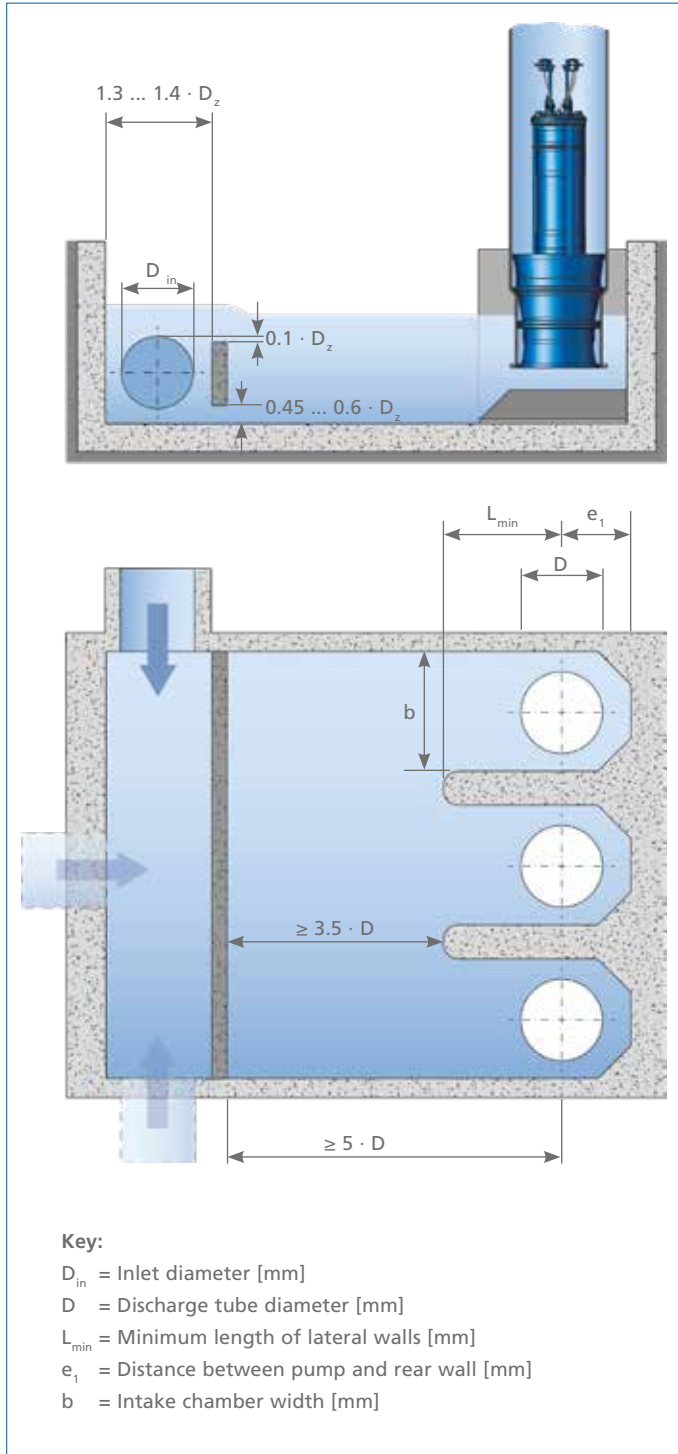


Fig. 49: Example of a pumping station with cross flow and curtain wall

If the direction of the flow (relative to the orientation of the pump intake chamber) discharged from the inlet channel changes, this must be corrected by appropriate devices, so-called “flow straighteners” (Fig. 49). While one function of flow straighteners is to dissipate the kinetic energy of the fluid entering the pumping station, their opening towards the floor ensures the flow moves in the direction specifically required. The result is a symmetrical approach flow into the pump chambers. If such a wall is not installed, the energy contained in the flow may cause vortices; in addition, the flow to the chambers is asymmetrical and therefore detrimental to trouble-free pump operation.

If the difference in height between the inlet channel and the pump sump is large, it may be necessary to eliminate the risk of aeration by incorporating a weir-type structure (Fig. 50).

A difference in height of more than 0.3 m [7] already provides sufficient reason to take appropriate measures. The adjacent illustration shows a pumping station with a considerable difference in height between the inlet channel and the pump sump and how this problem has been solved by fitting appropriate structures in the sump.

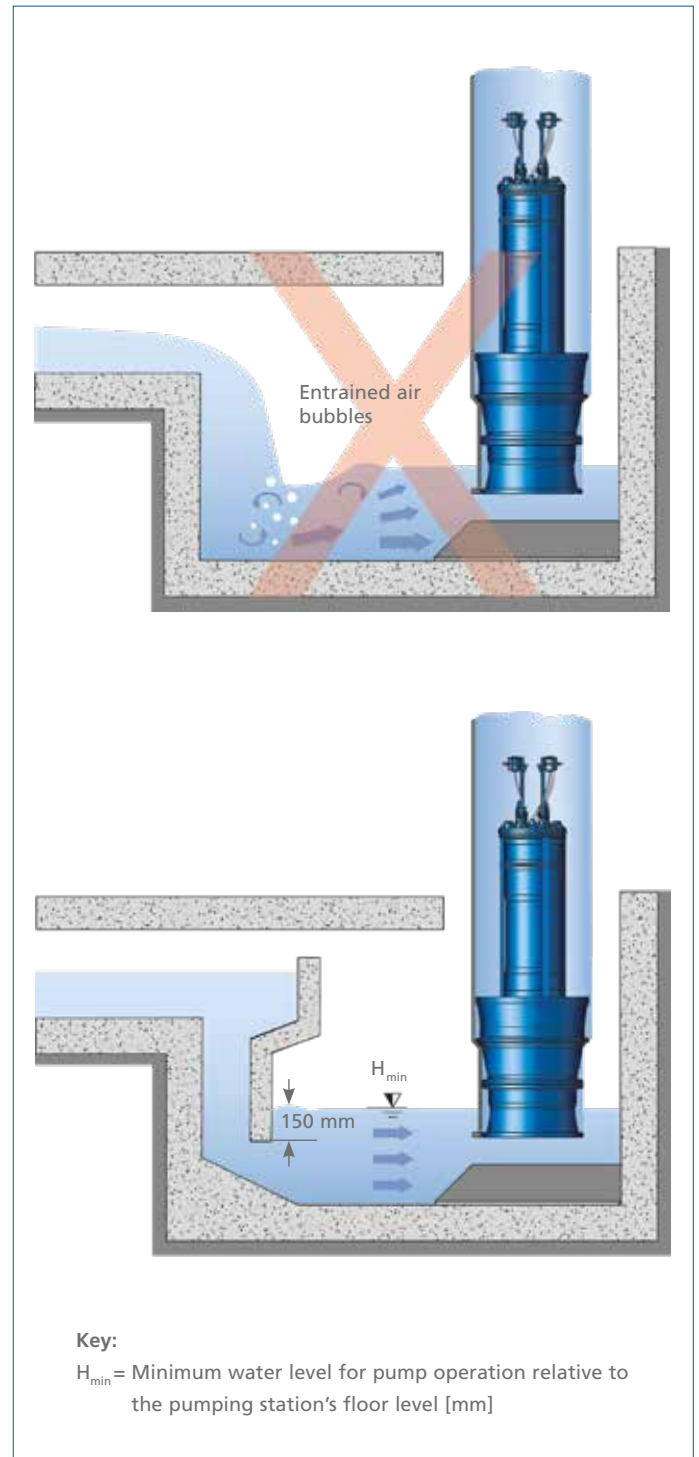


Fig. 50: Pumping station with weir-type structure

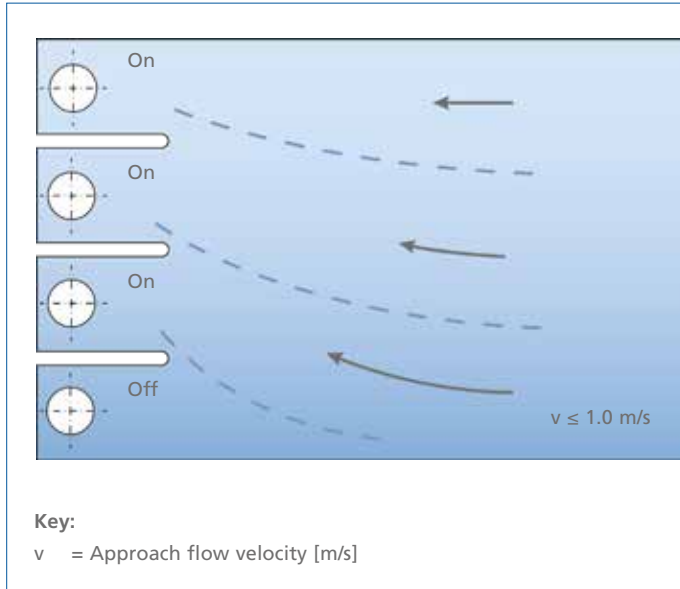


Fig. 51: Flow pattern developing with variable pump operation

Changes in flow direction can also be expected if only a few pumps are operating in a multiple-pump system (Fig. 51). Here preliminary assessment of the situation could help to decide whether a covered intake chamber should be preferred to an open one.

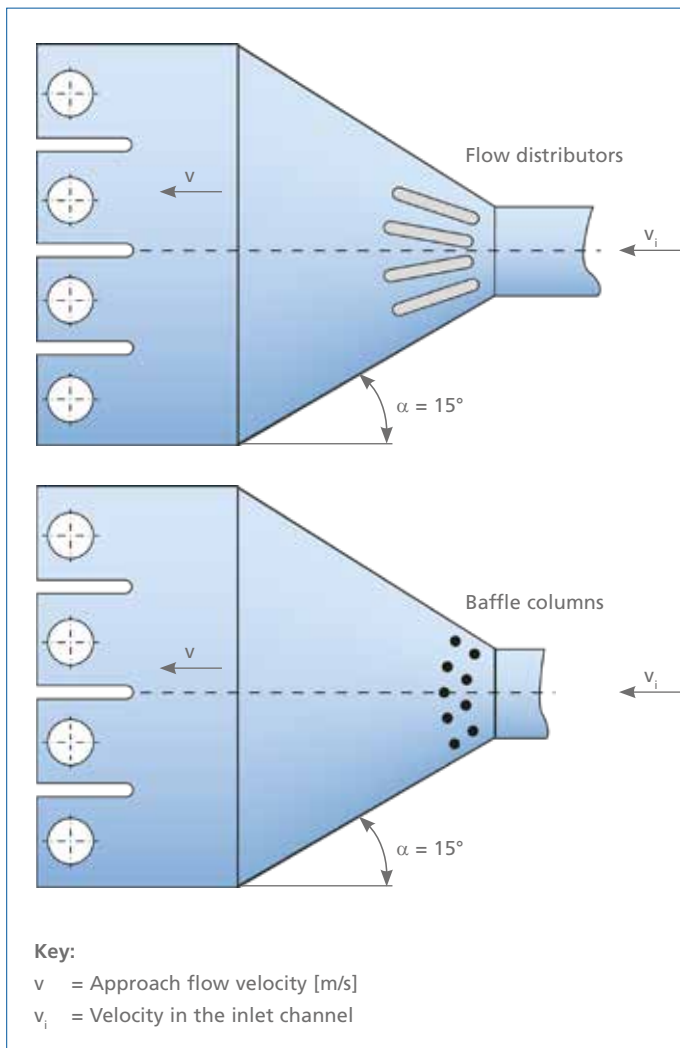


Fig. 52: Flow optimisation

If a divergence angle of more than 15 degrees is planned in the building to reduce inflow velocity  $v_i$ , additional steps such as the installation of flow distributors and/or baffles (deflectors) are necessary to prevent vortices caused by flow separation (Fig. 52). The feasibility of these measures depends on the nature of the fluid handled.



The intake situation from a channel is comparable with the abstraction of water from a river. Depending on the flow velocity, areas of flow separation can be expected where the water flows into the intake chamber area.

If it is not possible to provide a covered intake chamber, then it is important to markedly extend the chamber walls. As a reference value the pumping station designer can assume a factor 3 relative to the dimension  $L_{\min}$  given in the technical literature.

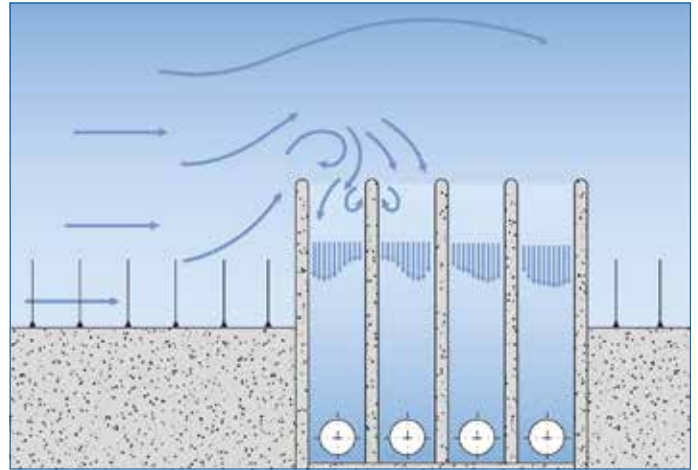


Fig. 53: Pumping station with open chamber for water abstraction from a river

If the fluid is taken from stagnant water, then cross flow is irrelevant. If the fluid level above the pumps is sufficient for the respective volume flow rate, i.e. a minimum water level  $t_1$  between the lowest water level in the water body and the intake chamber floor can be assured (see type series booklets), it is no problem to use open intake chambers.

Depending on the design of the pumping station's lateral walls, it may be possible to make them slightly longer than the intake chamber wall  $L_{\min}$  in order to reduce the influence of flow deflection on the outside intake chambers.

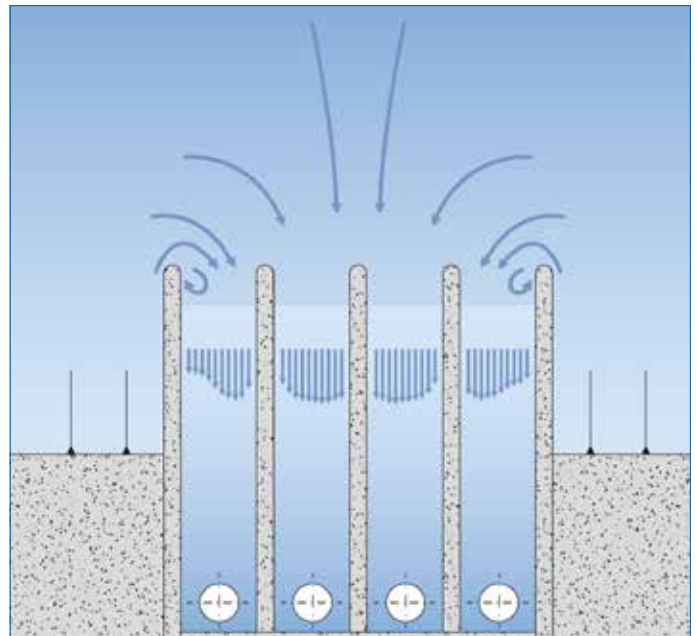


Fig. 54: Pumping station with open chamber for water abstraction from stagnant water

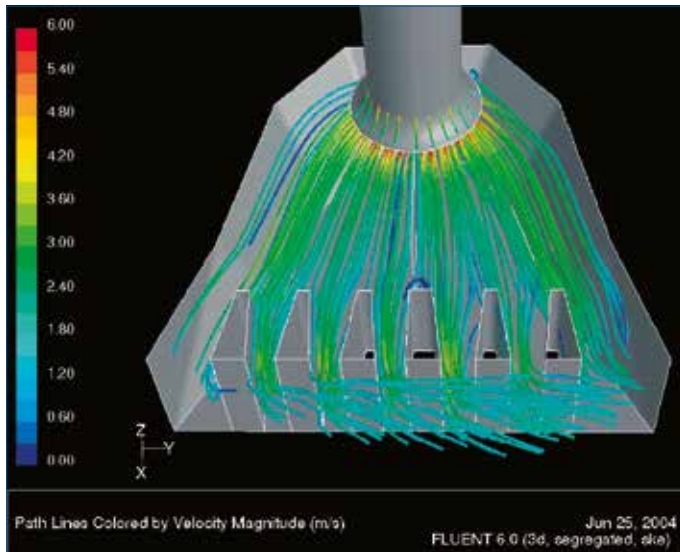


Fig. 55: Specially dimensioned intake chamber for cross flows of  $v = 1.8 \text{ m/s}$

## Solutions for special cases

If standard intake structures cannot be realised or the conditions in the pumping station do not correspond with the above-mentioned layouts, KSB's expertise should be utilised to find specific design solutions. The sooner advice is sought in such special cases, the better – and the higher the chance of identifying potential problems and of taking appropriate measures to find a practical solution.

To define these special cases more clearly, a few criteria, like for instance the maximum velocity in the approach zone of  $v > 1 \text{ m/s}$  and the large cross flows potentially associated with them must be mentioned. In such cases precisely dimensioned baffling and specially dimensioned intake chambers could possibly help to optimise the approach flow to the pump. The nature of the fluid handled is here again crucial, thus underscoring the need for an individually engineered solution. KSB has numerous successful designs in this field to its credit. The extent to which such measures are to be verified by model tests or CFD (Computational Fluid Dynamics) simulations should be individually determined.

## The necessity of model testing

The object of model testing is to simulate the flow of a planned pumping station in a scale model. It helps identify precisely where problematic conditions (vorticity, uneven velocity distribution, etc.) might arise and how to then influence these positively, where necessary. The high transparency of acrylic glass makes this material an excellent choice for the construction of suitable models (Fig. 56). In order to be able to transfer the flow conditions to the full-size structure, dimensionless numbers are applied in the design of the model. These characteristic coefficients describe the forces acting in the flow; they should be as identical as possible for both the model and the full-size structure. The most relevant forces are gravity, as well as those resulting from dynamic viscosity, surface tension and the inertia of the fluid in motion. The dimensionless numbers applied here are as follows:

<b>Reynolds number</b>	$Re = \frac{v \cdot d}{\nu}$	Formula (7)
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<b>Froude number</b>	$Fr = \frac{v}{\sqrt{g \cdot l}}$	Formula (8)
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<b>Weber number</b>	$We = \frac{\rho \cdot v^2 \cdot l}{\sigma}$	Formula (9)
---------------------	--	-------------

**Key:**

v	= Flow velocity [m/s]
d	= Hydraulic diameter [m]
$\nu$	= Kinematic viscosity [m <sup>2</sup> /s]
g	= Acceleration due to gravity = 9.81 m/s <sup>2</sup>
l	= Characteristic length (in the hydraulic system) [m]
$\rho$	= Density [kg/m <sup>3</sup> ]
$\sigma$	= Surface tension [N/mm <sup>2</sup> ]

Model testing is absolutely necessary when one or more of the criteria listed below apply to the intake structure or pump sump:

- The concept of the pumping station building deviates from proven layouts as regards chamber dimensions, piping layout, wall spacing, considerable changes in flow direction between inflow into the building and the approach flow to the pump, etc.
- The volume flow rate per pump is higher than 2.5 m<sup>3</sup>/s or 6.3 m<sup>3</sup>/s for the entire pumping station.
- The approach flow is asymmetrical and/or not uniform.
- Alternating pump operation in multiple-pump stations involves significant changes in flow direction.
- An existing pumping station has already created problems.

As these characteristics are to a degree interdependent, it is impossible to apply them at the same time in a scaled model. It is therefore important to find a compromise which helps achieve the optimum for a given application.



Fig. 56: Acrylic model of an Amacan P pumping station

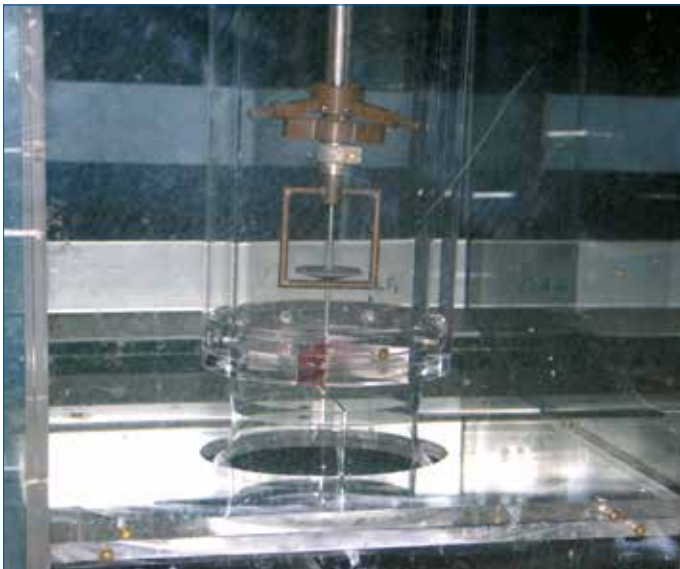


Fig. 57: Vortometer

## Test set-up

The geometry of the model must correspond with the original structure, taking into account the selected scale and the characteristic coefficients mentioned previously. This applies to the hydraulic part of the building structure and the pumps. Both the structure of the building and the pumps are constructed from transparent material. A model of the impeller is not required as the test aims to simulate only the flow approaching the impeller.

Instead of an impeller a vortometer (see Fig. 57) is employed whose rotational speed provides information on the development of vortices in the intake.

The flow velocities are measured at reference points across the model pump's entire suction cross-section via Pitot tube or laser. To judge vortex development the fluid surface as well as the wall and floor areas are observed. Vortex intensity in a given flow cross-section is visualised by means of dyes while their size is measured by the swirl angle  $\sigma$  of the vortometer. The following equation is applicable:

$$\sigma = \tan^{-1}\left(\frac{\pi \cdot d_m \cdot n}{u}\right)$$

Formula (10)

### Key:

- $\sigma$  = Swirl angle [°]
- $\pi$  = Pi = 3.14159265359
- $d_m$  = Pipe diameter (here the pump's suction pipe) [m]
- $n$  = Rotations of vortometer [1/s]
- $u$  = Axial flow velocity [m/s]

The surface vortices are classified according to Hecker in six categories (1 = low, 6 = very high, Fig. 60) and the submerged vortices in three categories (Fig. 61).

If one were only to look at the diagrams, these vortex formations appear relatively harmless. Yet vortex formation observed in model tests gives an idea of what could happen in a real structure. Unlike laboratory situations a real pumping station rarely deals with clear water and it is difficult to identify vortex action as the source of problem, especially when submerged vortices are involved.

The criteria which apply to this method of investigation may vary slightly depending on the pump type and the size and design of the pumping station.

### Evaluation of results

Before the design is finalised the measurement results should be confirmed by all parties involved: pumping station designer, end customer, pump manufacturer and the institution which conducted the tests.

Key criteria:

- The mean flow velocity at the defined measurement points of the suction cross-section should not deviate from the mean value by more than 10 %.
- The swirl angle should not exceed 5 degrees. A swirl angle of 6 degrees can be tolerated if it has occurred during less than 10 % of the period of observation.
- Surface vortices may only be accepted up to type 2 and submerged vortices up to type 1. In exceptional cases they can be tolerated if they have occurred during less than 10 % of the period of observation.

### In general the following applies:

Occurrences that have a minor effect in the model may be considerably more significant in the full-scale structure!

The tests must be concluded with a detailed report on the operating conditions investigated. The vortex formations and operating conditions observed (for the tested fluid levels in the building structure) have to be documented on video and made available to the party commissioning the tests.

KSB will support and co-ordinate project-related model testing upon request.



Fig. 58: Laboratory photo of a surface vortex type 6



Fig. 59: Laboratory photo of a surface vortex type 3

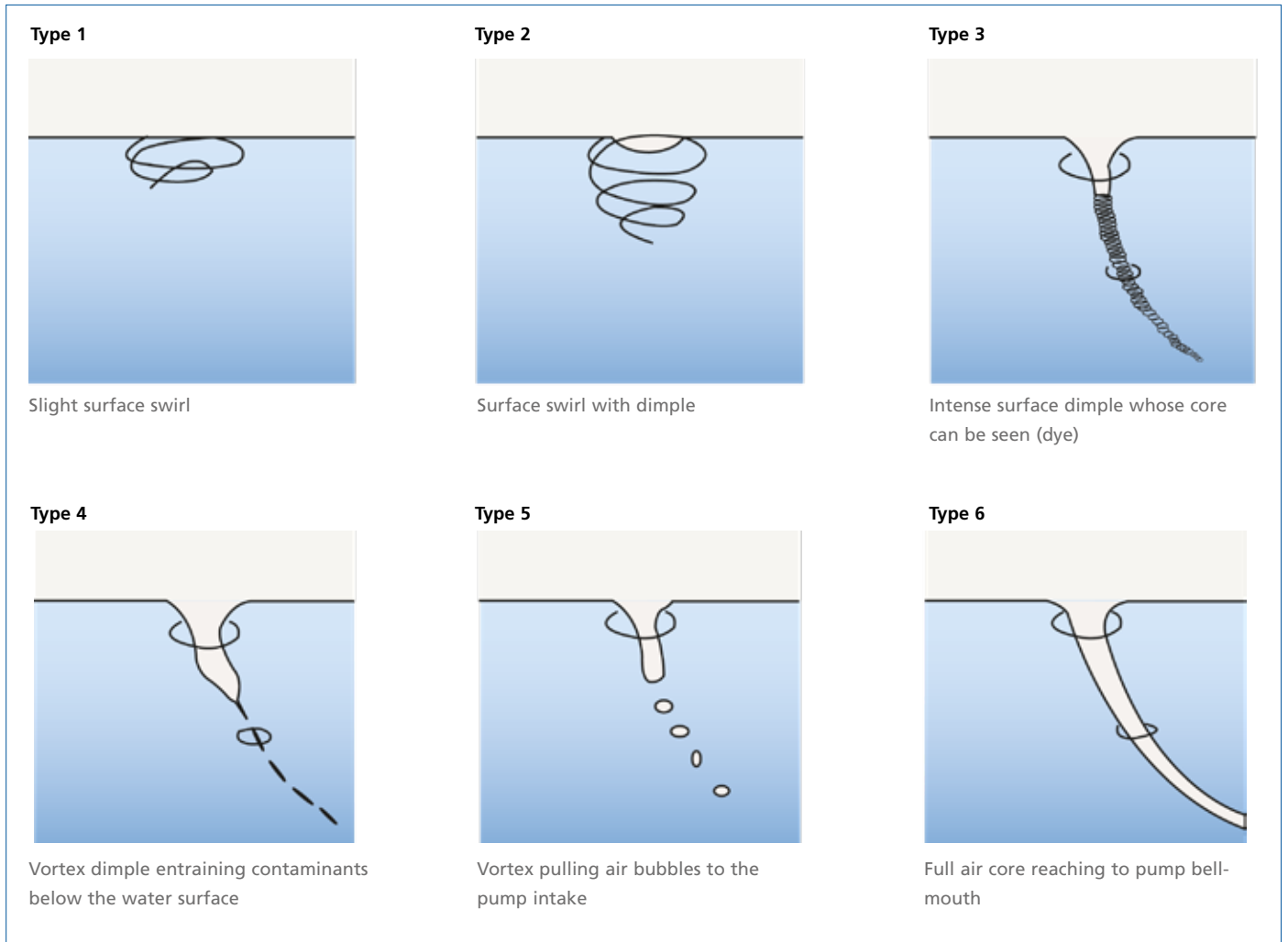


Fig. 60: Classification of surface vortices according to Hecker (Types 1 to 6)

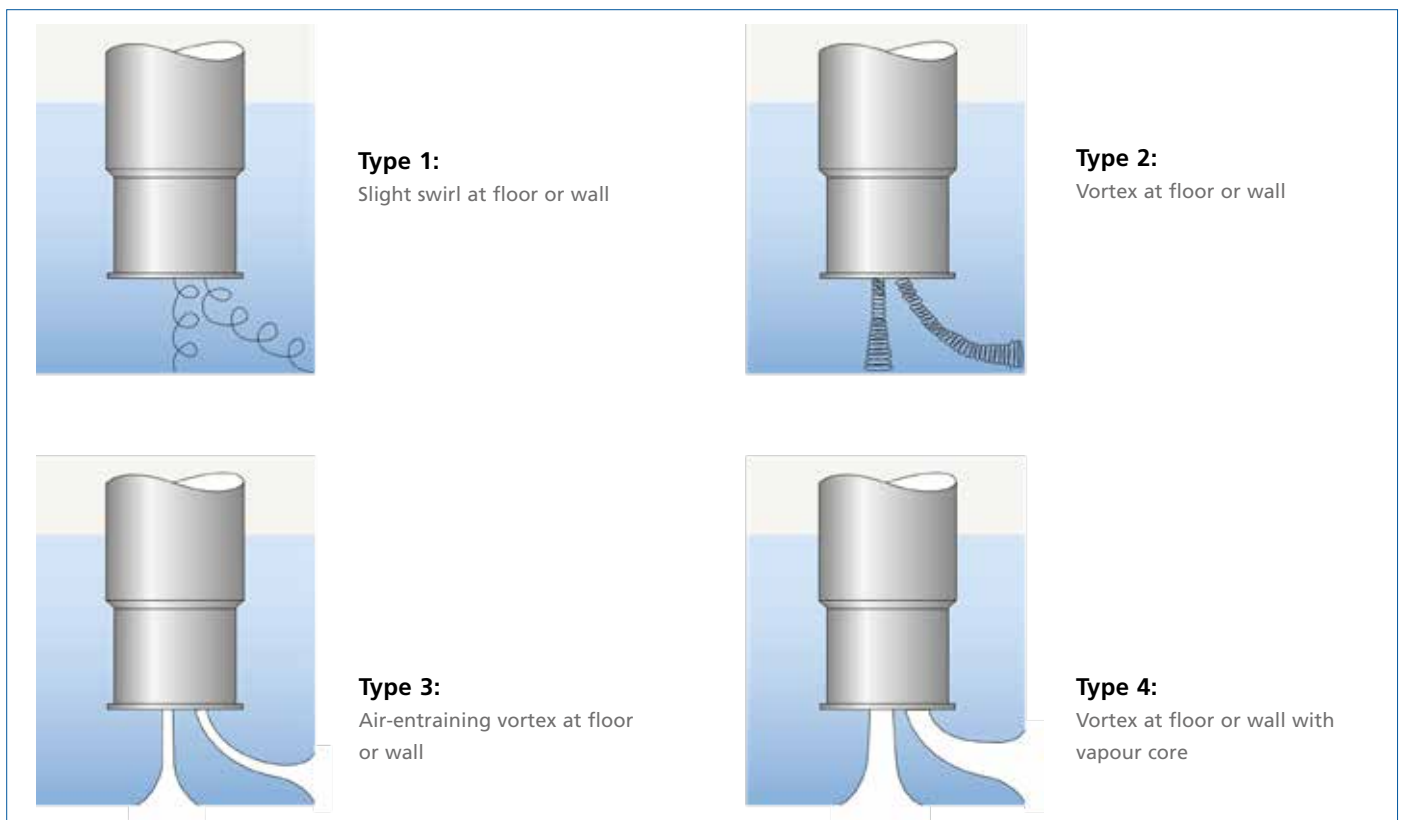


Fig. 61: Classification of submerged vortices according to Hecker (Types 1 to 4)



## The significance of CFD simulation

Numerical flow simulation (Computational Fluid Dynamics = CFD) is becoming increasingly important.

The software specially developed for this purpose is an effective instrument allowing relatively precise predictions of the flow conditions. The time and cost of flow modelling depends on the

- Size of the flow area to be modelled
- Desired geometric resolution
- Computer performance
- Form of presentation (report)
- and scope of results.

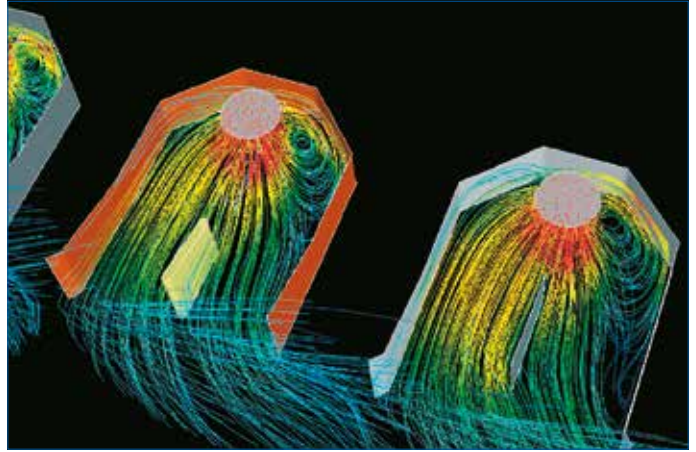


Fig. 62: Flow patterns in Amacan intake chambers

### Methodology

The mathematical description of fluid flows is based on the Navier-Stokes equations. They describe the processes at each point of a flow by means of partial differential equations for mass, energy and momentum.

The calculation of each spatial point in a flow is not feasible as this would result in an infinite number of calculations. A grid is generated instead, whose nodes are calculated. The grid model is then processed further to provide information on the pressure and velocity distribution, which can then be subjected to numerical and/or graphical analysis. In modelling, the distances between individual nodes may partly differ; they depend on the flow velocity gradients.

The calculated nodes lie closer together near walls and corners, which are considered as discontinuities from a fluid dynamics point of view. In areas with low velocity gradients it is not a problem to increase the distances. In addition, assumptions on the distribution of turbulence are made at the nodes. The task of a CFD specialist is to choose the “correct” turbulence model. It takes a lot of experience to be able to create an adequate model and to be able to accurately interpret the results obtained.

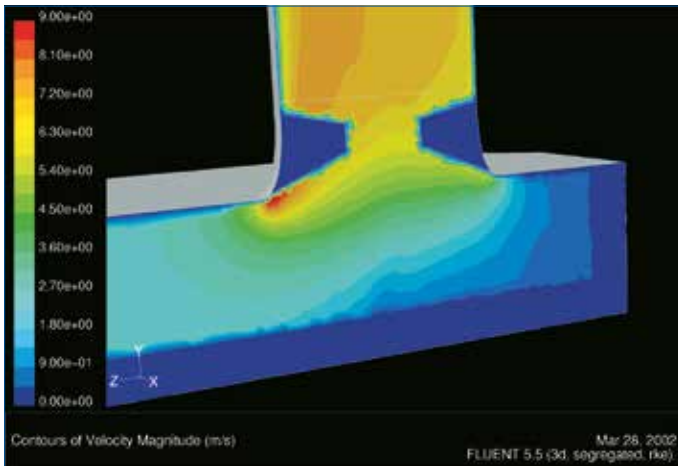


Fig. 63: Simulation of approach flow to discharge tube

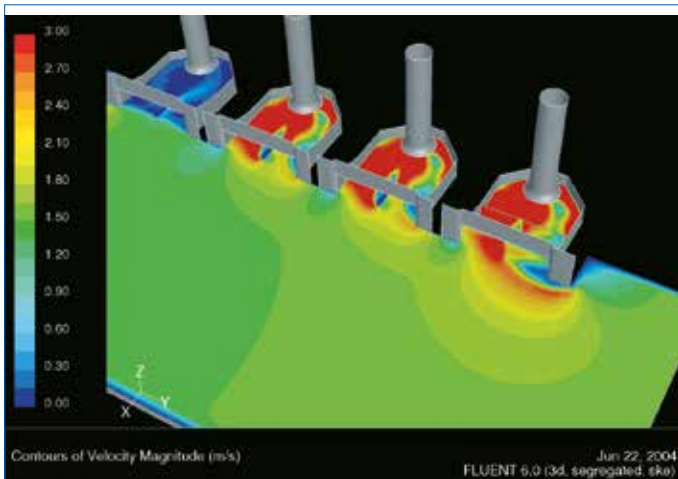


Fig. 64: Simulation of pumping station with several pumps

CFD simulation is perfectly suited to evaluating flows in intake structures and pump sumps, especially as it can also be used to make a very exact analysis of the influence individual pumps have on the flow pattern in multiple-pump systems. Problems are more often caused by the fact that surface and submerged vortices and asymmetrical approach flows do not always exhibit steady behaviour and are therefore difficult to predict exactly.

At KSB CFD simulation is a well-established engineering tool that has been used for years. The fact that CFD calculations have been proven to conform well with model testing in past investigations allows more accurate predictions to be made today on potential flow situations and enables pumping stations to be more systematically optimised. In complicated cases, however, physical model testing is to be preferred to CFD calculations for building structure investigations. In the future the use of both CFD simulations and model testing will significantly reduce the overall costs of pumping station investigations.

## Screening equipment

The installation of screening equipment is required for trouble-free pump operation: Depending on the type and origin of the fluid handled it is desirable to install coarse screens (bars spaced between 5 and 30 cm apart) (Fig. 65) and/or fine screens (bars spaced between 5 and 20 mm apart) as well as shingle traps mounted upstream of the screens if needed (Fig. 67). The screens and traps should be cleaned automatically during pump operation using appropriate mechanical equipment (Fig. 66). In applications where surface water from rivers, lakes and channels is pumped or in storm water pumping stations the installation of screening equipment is an absolute must.

The fact that river water in particular contains shingle and sediment is often overlooked. Under conditions of long-term operation, however, failure to fit the appropriate screening equipment upstream of a pumping station will lead to sand accumulation and considerable sedimentation in stagnation zones at and within the building, as well as to increased wear to centrifugal pumps. Mechanical damage to the impeller and other pump parts can likewise not be ruled out (Fig. 72).

Where the screens are to be accommodated in the pumping station layout is the designer's decision. The screening equipment is either mounted upstream of the pumping station or sump to prevent coarse material from entering the building, or single screens are directly integrated into the intake chamber. Selecting the latter option may necessitate longer chambers due to the slightly reduced flow cross-section which results from integrating the screen. Downstream of the screening equipment the velocity distribution developing across the flow cross-section should be even and therefore favourable for pump operation, provided the screen is largely free from any trapped material (Fig. 66). When establishing the minimum fluid level  $t_1$  in the pump sump, it is also necessary to take into account that a screen filled with trapped material creates flow resistance, resulting in different fluid levels upstream and downstream of the screen. The water level downstream of the screen must not fall below the permissible minimum water level  $t_1$  for the pump's operating point.

Half of the impeller's free passage should be used as a reference value to determine the permissible maximum distance between the screen bars. This value can be found in the respective pump characteristic curve (see type series booklet or selection software).



Fig. 65: Coarse screens upstream of an Amacan pumping station (water abstraction from a river)



Fig. 66: Screen with automatic cleaning system

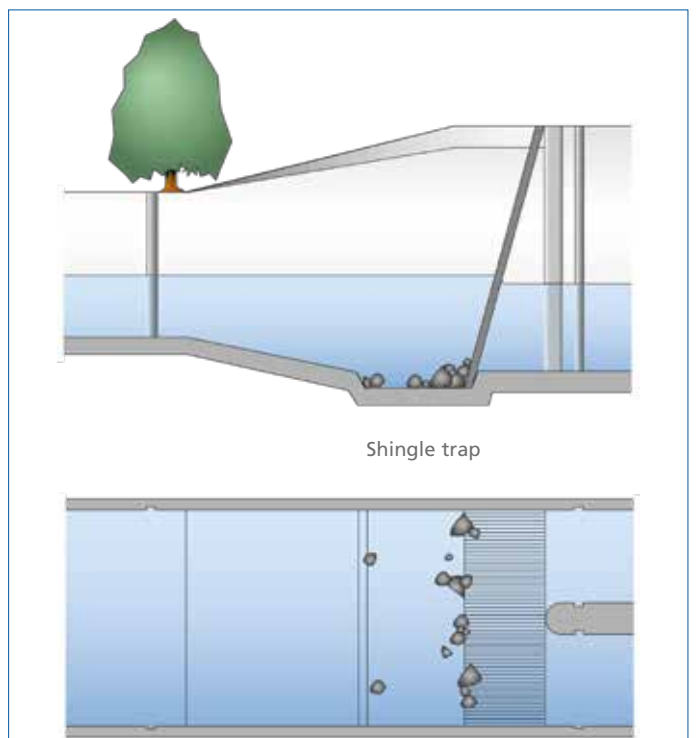


Fig. 67: Shingle trap upstream of pumping station

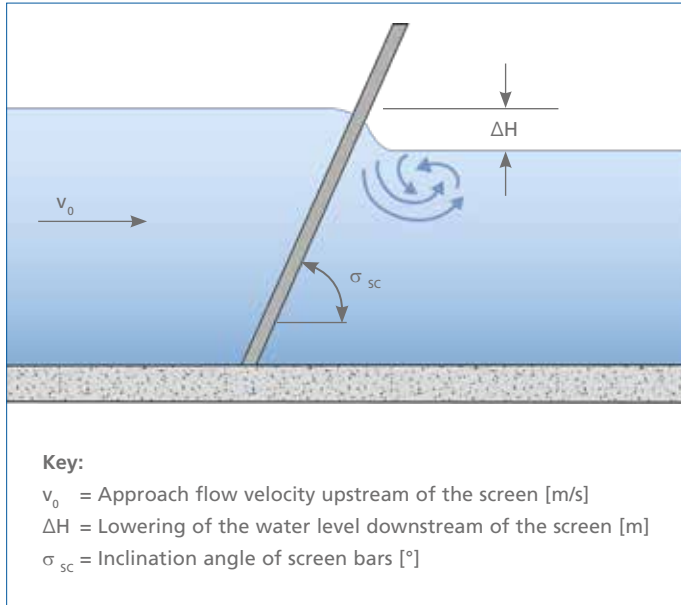


Fig. 68: Flow through screen, without lowered floor

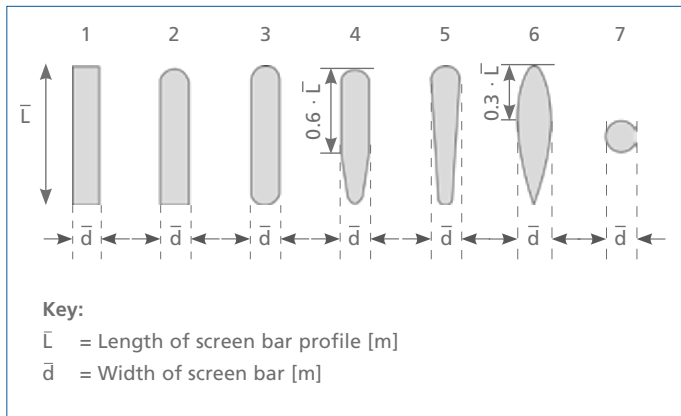


Fig. 69: Shape of screen bars

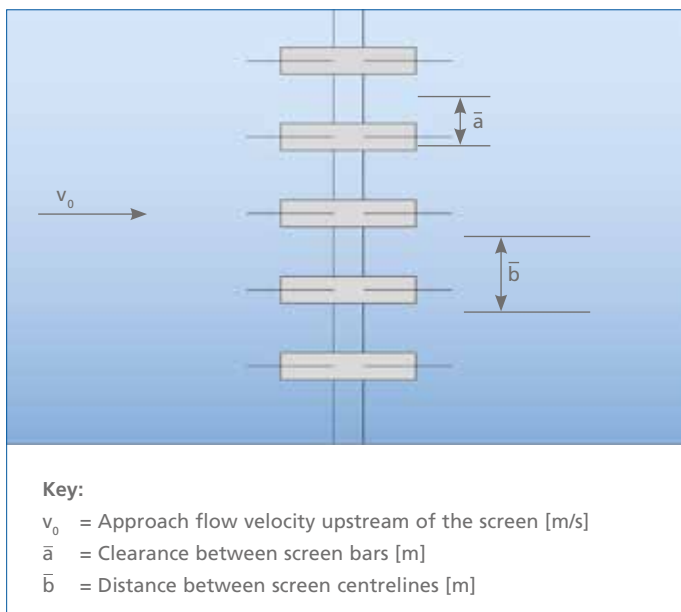


Fig. 70: Screen layout drawing

To evaluate the screen’s influence on the water level directly upstream of the pumps it is advisable to use Hager’s simplified calculation [10], if a detailed screen selection procedure is not being undertaken.

Applying this calculation will result in the lowering of the water level downstream of the screen  $\Delta H$  as expressed in the equation:

$$\Delta H = \xi_{sc} \cdot \frac{v_0^2}{2g} \quad \text{Formula (11)}$$

$$\text{where } \xi_{sc} = \beta_{sc} \cdot c_{sc} \cdot \sin \sigma_{sc} \cdot \zeta_{sc} \quad \text{Formula (12)}$$

- Key:**  
 $\Delta H$  = Lowering of the water level downstream of the screen [m]  
 $\xi_{sc}$  = Loss coefficient of screen  
 $v_0$  = Approach flow velocity upstream of the screen [m/s]  
 $\beta_{sc}$  = Loss coefficient for screen bar geometry  
 $c_{sc}$  = Correction factor for the cleaning method and screen clogging  
 $\sigma_{sc}$  = Inclination angle of screen bars [°]  
 $\zeta_{sc}$  = Coefficient for screen geometry  
 $g$  = Acceleration due to gravity = 9.81 m/s<sup>2</sup>

The following values can be applied for the following different bar shapes (Fig. 69):

Shape	1	2	3	4	5	6	7
$\beta_{sc}$	1	0.76	0.76	0.43	0.37	0.3	0.74

Table 2: Loss coefficient for the screen bars’ geometry

$\bar{L}$  is the length of the screen bar profile and  $\bar{d}$  the width. If the ratio of  $\bar{L}/\bar{d}$  is approx. 5 and the condition  $\bar{b}/\bar{a} > 0.5$  is satisfied, the formula (12) for  $\zeta_{sc}$  can be simplified and expressed as follows:

$$\xi_{sc} = \frac{7}{3} \cdot \beta_{sc} \cdot c_{sc} \cdot \sin \sigma_{sc} \cdot \left[ \frac{\bar{b}}{\bar{a}} - 1 \right]^4 \quad \text{Formula (13)}$$

- Key:**  
 $\xi_{sc}$  = Loss coefficient of screen  
 $\beta_{sc}$  = Loss coefficient for screen bar geometry (Table 2)  
 $c_{sc}$  = Correction factor for the cleaning method and screen clogging  
 $\sigma_{sc}$  = Inclination angle of screen bars [°]

The following applies for  $c_{sc}$  :

- $c_{sc} = 1.0$  for unobstructed screens
- $c_{sc} = 1.1 \dots 1.3$  for mechanically cleaned screens
- $c_{sc} = 1.5 \dots 2.0$  for manually cleaned screens



In order to compensate for the losses  $\Delta H$  occurring as the flow passes the screen (Fig. 71), the floor of the intake structure or channel is often lowered by the value  $\Delta z$  downstream of the screen:  $\Delta H = \Delta z$

The values usually applied for losses through screens range between approx. 5 cm for mechanically cleaned screens to approx. 10 cm for manually cleaned screens.

For detailed screen selection, the method according to Idelchik [11, p. 504 ff] is recommended. This method is most appropriate when the influence of oblique flow to the screen is also to be taken into account or if the screen bars are markedly different from what was illustrated in Fig. 69.

Screens are often integrated directly into intake chambers. Each pump thus has its own screen. The distance between the screening equipment and the pump's discharge tube should be at least  $4 \cdot D$  ( $D$  being the discharge tube diameter).

If it is assumed that the flow might approach the screen from the side and the influence on the water level downstream of the screen might be difficult to predict, preventive measures are then advisable. Extending the intake chamber wall and positioning the screen in the intake chamber area would then achieve better defined and uniform approach flow conditions for the pump and screen.

Automatic screen cleaning should be preferred (Fig. 73). To activate the cleaning process it is possible to make use of the difference in fluid levels upstream and downstream of the screen. This ensures that the cleaning process is activated as required. Manual cleaning is unfavourable for pump systems in continuous operation, as the fluid level has to be regularly checked and the screen cleaned by the operating staff. Timer-controlled cleaning is also not sufficiently reliable.

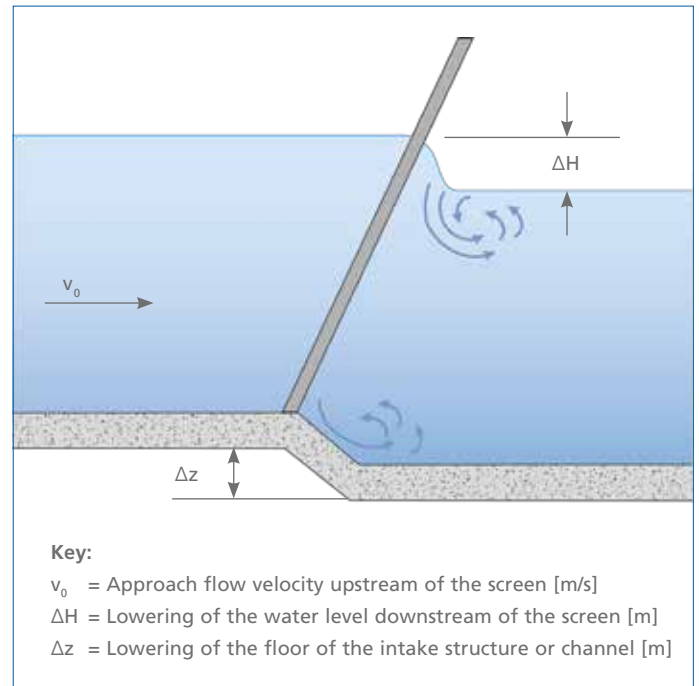


Fig. 71: Flow through screen, with lowered floor



Fig. 72: Wood inside the diffuser casing of an Amacan pump



Fig. 73: Pumping station with automatic screens

# Discharge Tube Designs

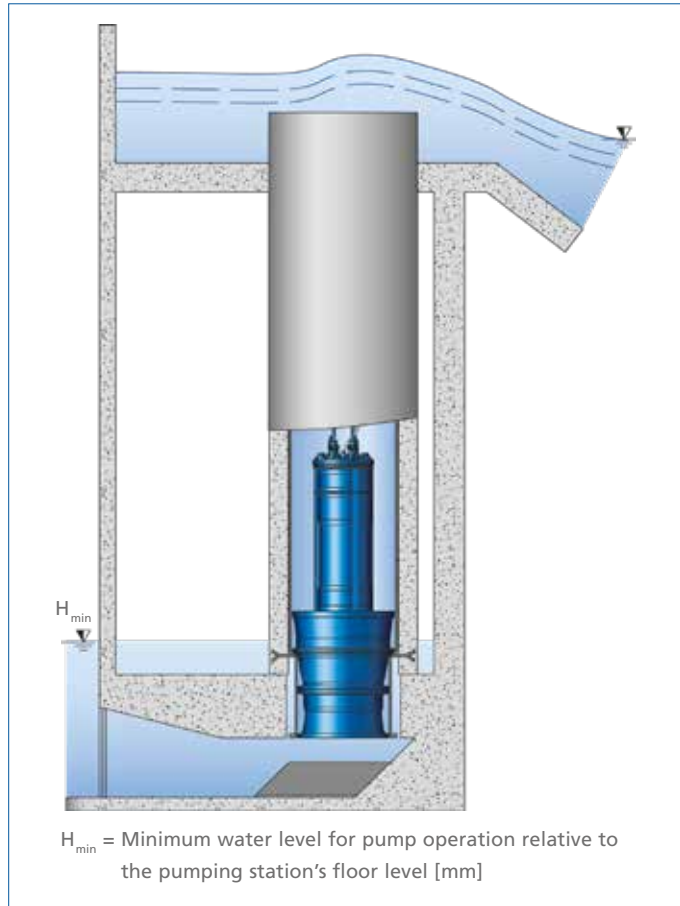


Fig. 74: Installation type A

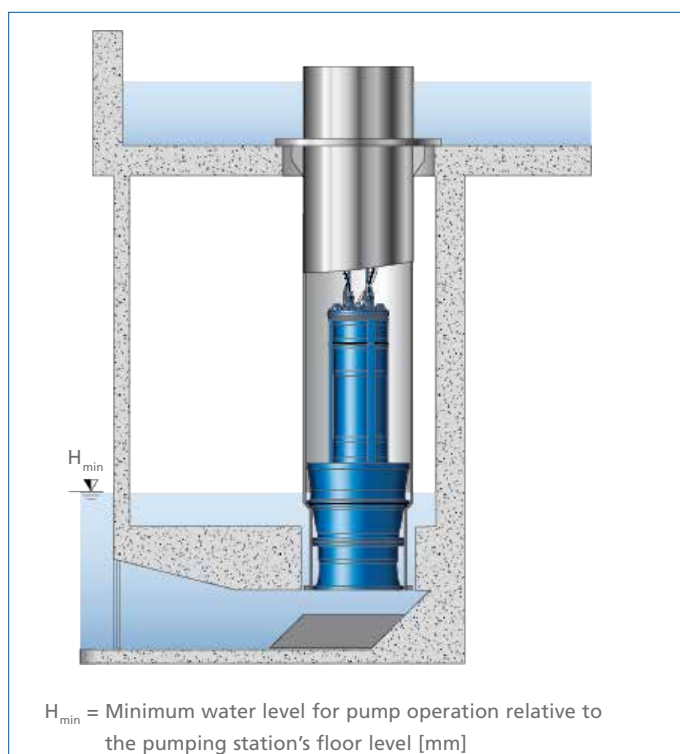


Fig. 75: Installation type BG

The design configuration of Amacan pumps allows a wide variety of installation variants to be chosen with practically no boundaries set on a designer's creativity. Discharge tubes are not only made from metal materials and glass fibre reinforced plastics (GFRP), they can also be constructed with concrete elements. No matter which installation variant is chosen, it is important that the pump's seating surface in the tube, shaped as a 45-degree slope, is executed accurately.

## Design variants

### Installation type A (Fig. 74)

The seating ring is set in concrete in the intake chamber area, then the concrete tube elements are used to construct the discharge tube. Such a design variant may be suitable for use in simple drainage and irrigation pumping stations.

### Installation type BG (Fig. 75)

This illustration shows a covered intake chamber. Here the discharge tube is, however, made from metal. For this variant it is necessary that at the upper building level the discharge tube is appropriately sealed against the fluid handled and supported to withstand the mechanical forces. The upper discharge tube edge has to be designed in accordance with the run-off conditions of the discharged fluid and the maximum flow velocities within the tube itself.



### Installation type BU (Fig. 76)

This discharge tube variant can, of course, also be employed in conjunction with open intake chambers. The final decision on the intake chamber design is taken on the basis of the required minimum water level relative to the volume flow rate of the pump and the approach flow direction (see diagram  $t_1 = f(Q)$  in the type series booklet or selection software).

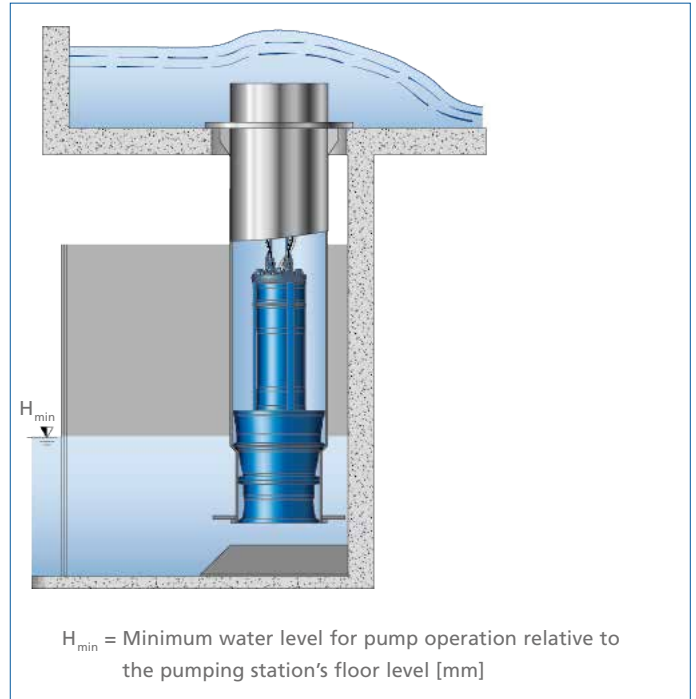


Fig. 76: Installation type BU

### Installation type CG (Fig. 77)

The next type of installation presented here is the underfloor installation. The horizontal discharge tube outlet is situated below the upper building level. An additional, above-floor building structure, which is necessary in conventional pumping stations, is not required here, resulting in a cost advantage.

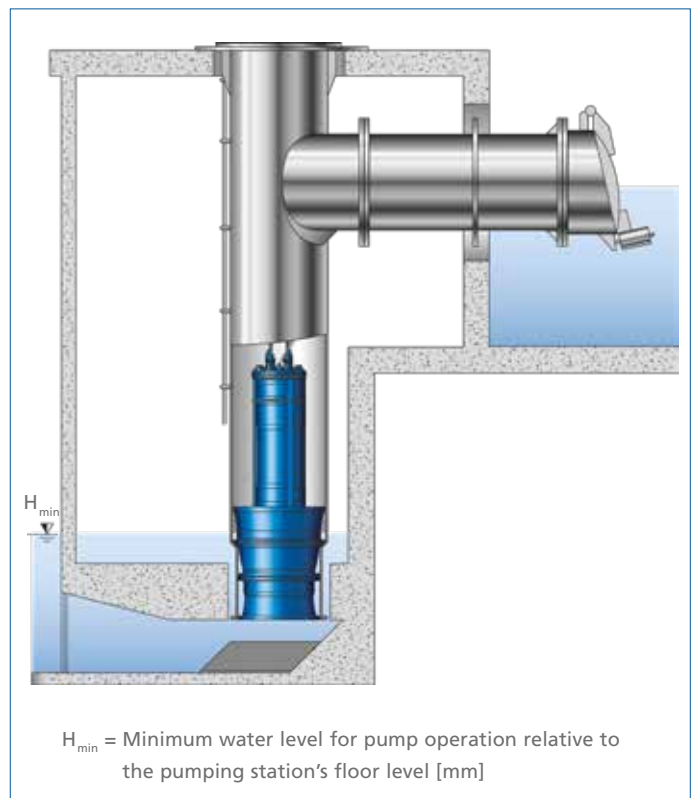


Fig. 77: Installation type CG

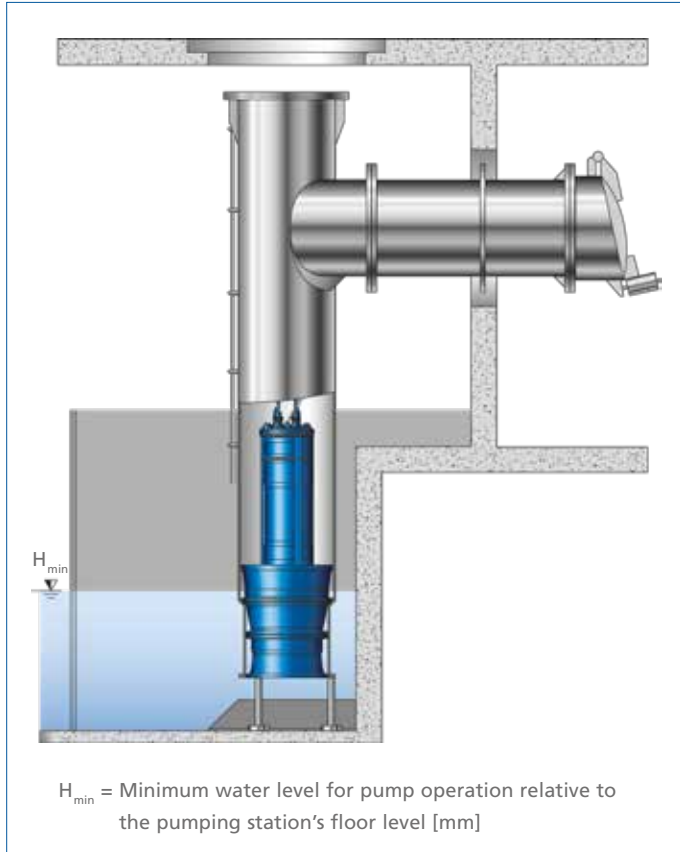


Fig. 78: Installation type CS

**Installation type CS (Fig. 78)**

If the area above the pumping station is intended for vehicular traffic, the discharge tube can, if necessary, be fitted with support feet resting on the floor underneath the inlet. After the discharge tube has been set up and mounted, the installation area is closed with a cover traversable for vehicles. The electrical cables are routed under the floor to the power supply.

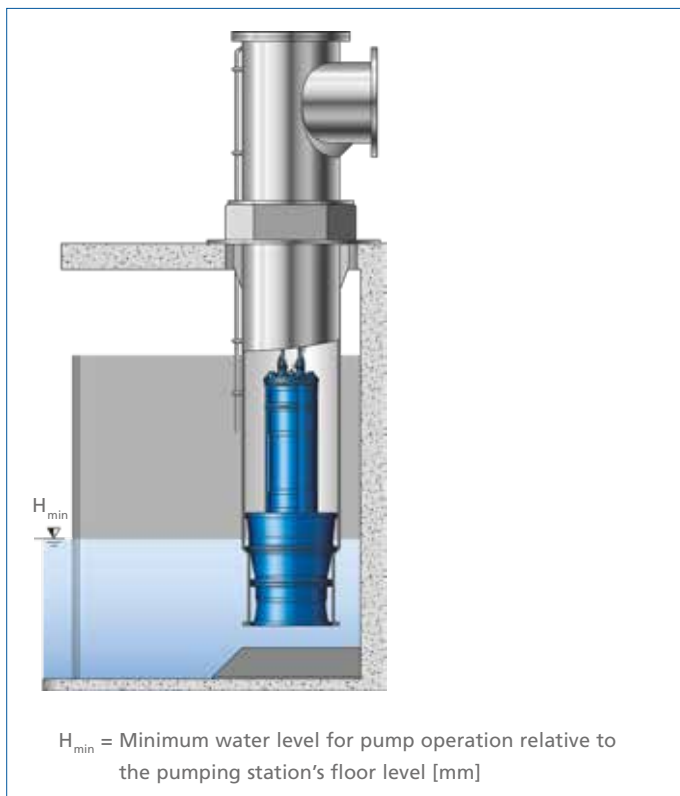


Fig. 79: Installation type DU

**Installation type DU (Fig. 79)**

If some systems require the discharge flange to be connected above the floor, this installation type can be chosen. A plate is mounted on the upper building level to accommodate the discharge tube forces. When deciding on the size of this plate it is important to consider the maximum forces developing during pump operation (pump weight, piping forces, effective moments, etc.).

## Details on discharge tube design

The manufacturing quality of the discharge tube is important for the proper functioning of the pump or pumping station. As the pump is centred and positioned in the discharge tube on a 45-degree bevel, resting on a rubber ring provided at the pump casing (the pump is seated by its own weight plus the axial thrust developed during pumping), particular attention must be given to this area during manufacturing (Figs. 80 and 81). Poor concentricity and surface finish may cause the pump to rest on some points but not all of the inclined seating surface, resulting in inadequate sealing with some flow passing back to the suction side. As a consequence, the pump does not achieve the volume flow rate required for the connected system.

If the tube is a welded metal sheet construction, it is important to ensure that the welded seams in the 45-degree seating surface are level and true (Fig. 81). The entire discharge tube should additionally be checked for concentricity. As thin metal sheets can be deformed by the welding process, static and dynamic calculations should be applied to size the metal sheet thickness of the discharge tube. This avoids over- and undersizing as well as problems with natural frequency. Alternatively, it is also possible to make this seating surface as a turned part and to weld it to the discharge tube at the top and bottom (Fig. 80). Making long discharge tubes from individual segments bolted together at their respective flanges is recommended to improve concentricity. These tubes are easy to install at site and the flanges provide additional mechanical stability in the radial direction.

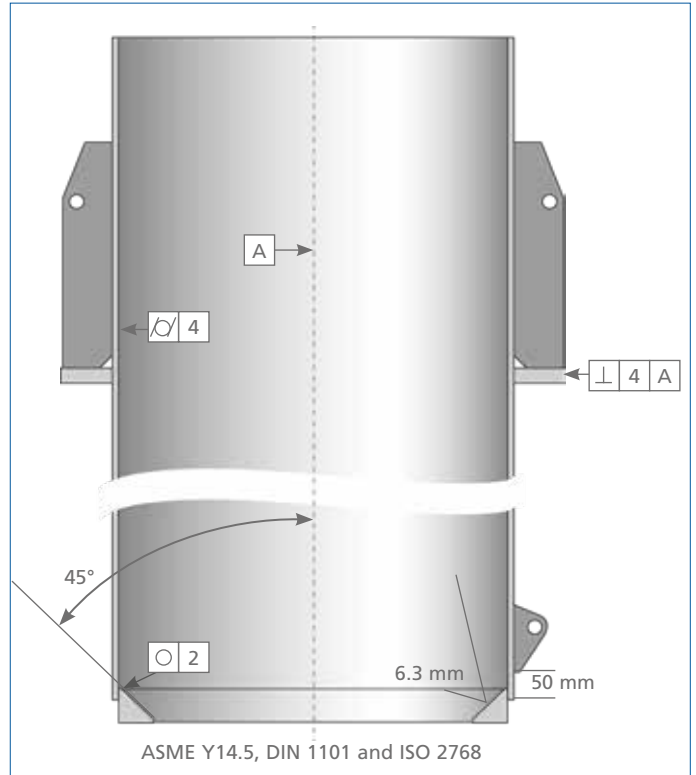


Fig. 80: Seating surface of pump in discharge tube for Amacan K

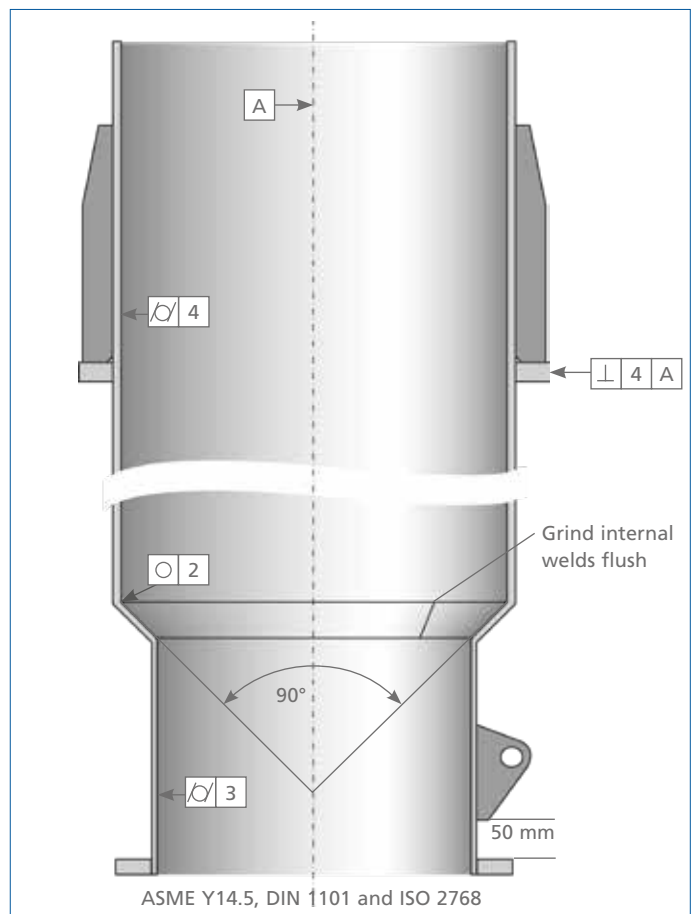


Fig. 81: Discharge tube in sheet metal construction for Amacan P / S

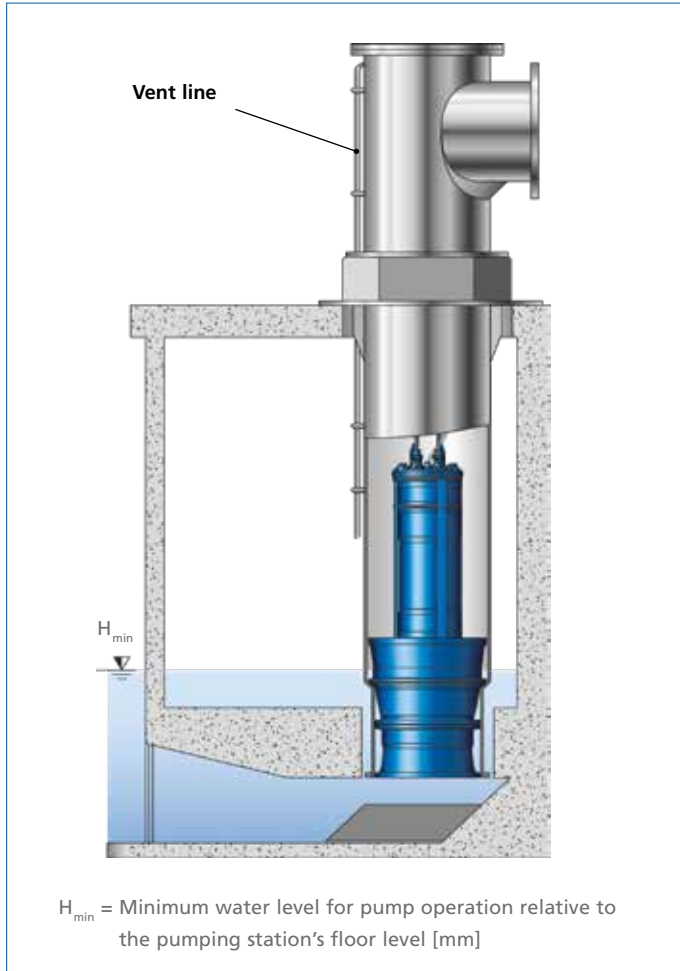


Fig. 82: Vent line on discharge tube

For all discharge tubes closed with a cover it is vital to provide an adequate venting device. If this is not provided, a cushion of compressed air will develop in the upper discharge tube section. This has an effect similar to that of a spring and prevents the pump from running steadily. In extreme cases, vibrations may be caused which affect the entire discharge tube. As a remedial measure, a vent line is laid from the upper end of the tube down to the sump, or the discharge tube cover is fitted with a venting and aeration device. If a vent line is to be fitted, the additional space required must be taken into account when planning the access openings.

If the installation depth of the discharge tube is more than 4 metres, the tube should be centred and/or braced. The dimensions for such centring/bracing devices can be derived from the static and dynamic calculations.

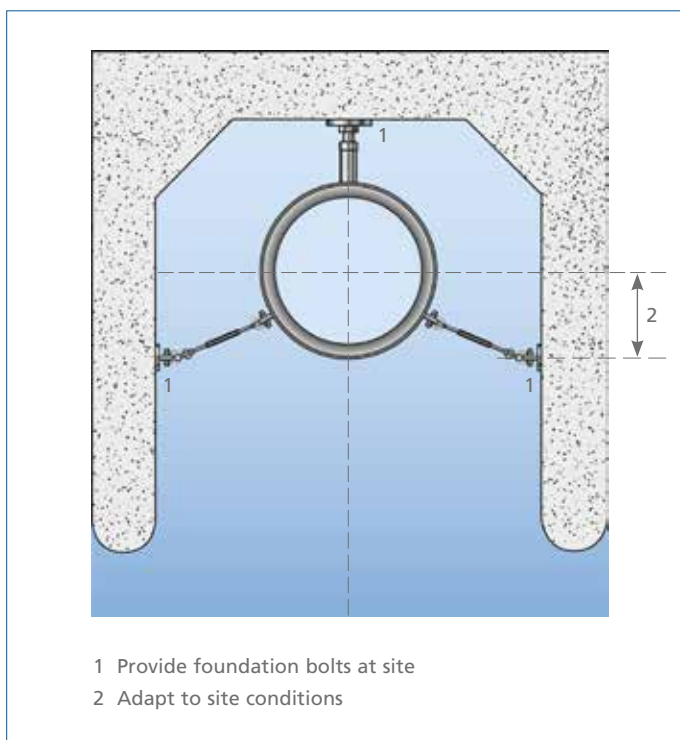


Fig. 83: Discharge tube bracing with turnbuckles

## Cable Connections

The pumps of the Amacan series are all equipped with an absolutely watertight cable entry system. This KSB patented system protects against the fluid handled penetrating the motor space or terminal box of the pump, if the cable insulation has been damaged during installation or operation. The insulation of the individual cable cores is stripped and the wire ends are tinned. This section is fixed in the cable gland system with spacers and then embedded in synthetic resin. A rubber gland provides additional sealing. This sealing principle is used for both power and control cables (Fig. 84).

When the pump is installed in the discharge tube, it is necessary to mechanically support the cables' own weight and at the same time protect them against flow turbulence. For this purpose KSB has developed a patented cable holder (Fig. 87). The cables (power and control cables) are attached to a stainless steel support rope using rubber profiles (Fig. 88). The support rope is then fastened to the discharge tube cover or to a cross bar in the case of an open discharge tube using a turnbuckle and shackle. This guarantees that the cables have a long service life and the cable entry into the motor housing is absolutely tight.

To ensure the cables are smoothly routed through the discharge tube cover either welded-in sleeves (Fig. 85) or shaped rubber grommets are used. The choice of cable passage depends in the main on the type of discharge tube and the system pressure. If the tube variant is one closed with a cover, the cables must be supported by a separate holder underneath the cover to support the cables' own weight and protect them against flow turbulence in the discharge tube (Fig. 85). If the discharge tube is open, the cables are routed vertically out of the tube and are then attached to a cross bar.

If Amacan pumps are installed at greater installation depths, then additional lateral supports should be fitted to hold the cable support rope in position (Fig. 87). The purpose of these supports is to reduce the influence of turbulent flow on the rope. These supports rest against the discharge tube wall.

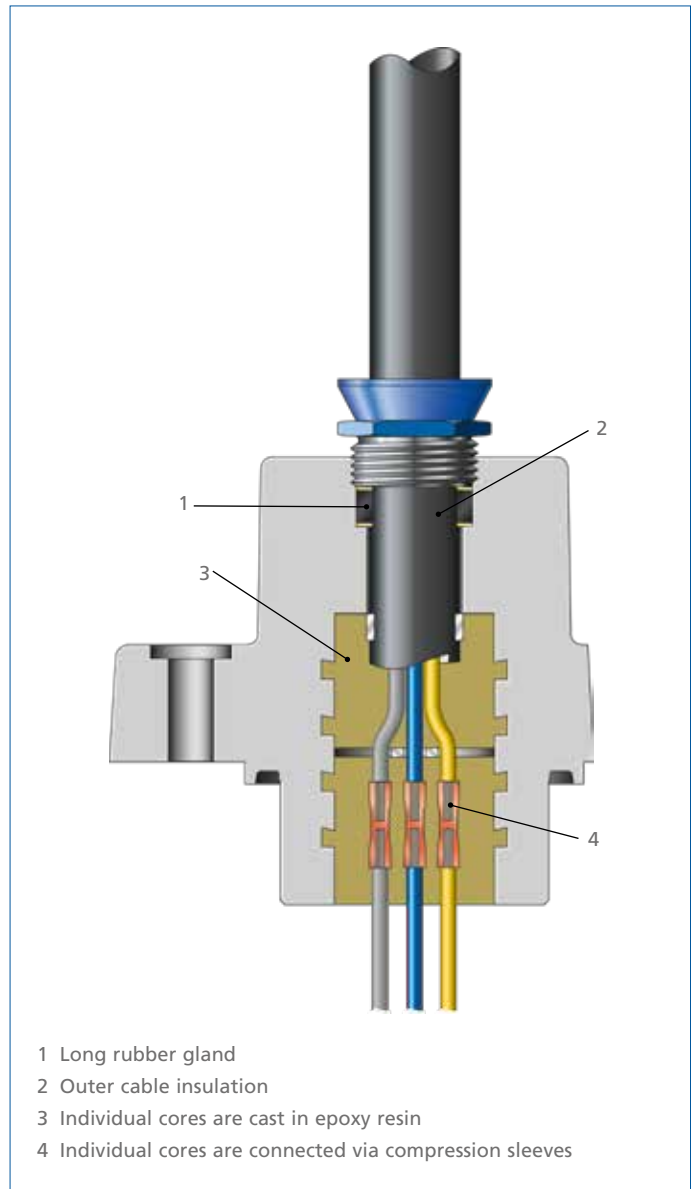


Fig. 84: Sectional drawing of an absolutely watertight cable entry system on a pump

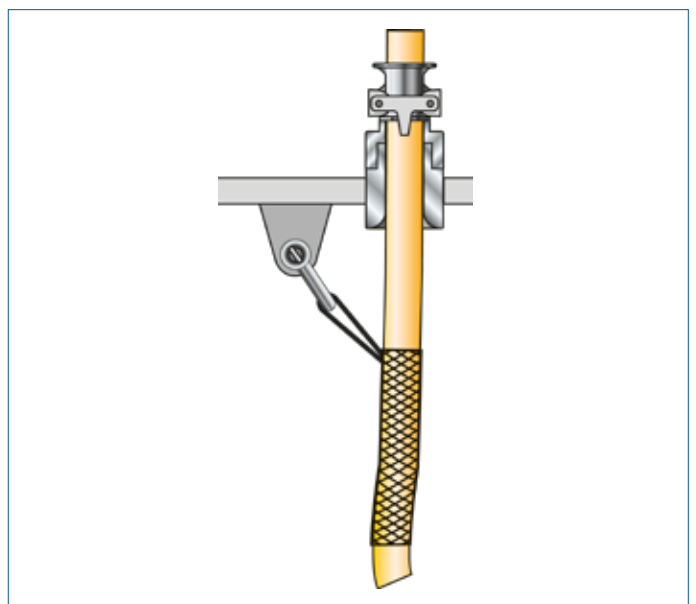


Fig. 85: Cable suspension and cable entry into discharge tube



Fig. 86: Lowering an Amacan into the discharge tube

When ordering the pump it is necessary to specify the exact installation depth so that the precise length of the cables and ropes as well as the number of supports can be determined. If the specifications of both planning and execution stages differ, the following two situations may arise:

- If the support rope is too short, the pump will not be firmly seated in the discharge tube and the reaction moment of the pump may damage the cables during start-up.
- If the cables are too long or not tight enough, the flow may cause the lifting lugs of the cable assembly to hit against the discharge tube thereby damaging the discharge tube, support rope and cables.

In order to determine the correct number of lifting lugs on the support rope for crane hook attachment, it is also important to know the lifting height of the crane.

If the components described above are not ordered along with the pump, other solutions may have a very negative influence on the pump's functioning. Power and control cables are, for instance, very often attached to the support rope with simple cable straps; this, however, will lead to the destruction of the cable insulation and/or core breakage inside the cable during pump operation.

For installation depths greater than 5 m the cable holder and support rope design becomes increasingly important for trouble-free pump operation.

List of components

Part No.	Description	Material
59-8	Turnbuckle	Stainless steel
59-17.2	Shackle	Stainless steel
59-47	Lifting lug	Stainless steel
59-24	Rope, low-rotation design	Stainless steel
720	Fitting	EPDM
59-17.1	Shackle	Galvanised steel (stainless steel optional)
59-7	Support	GFRP

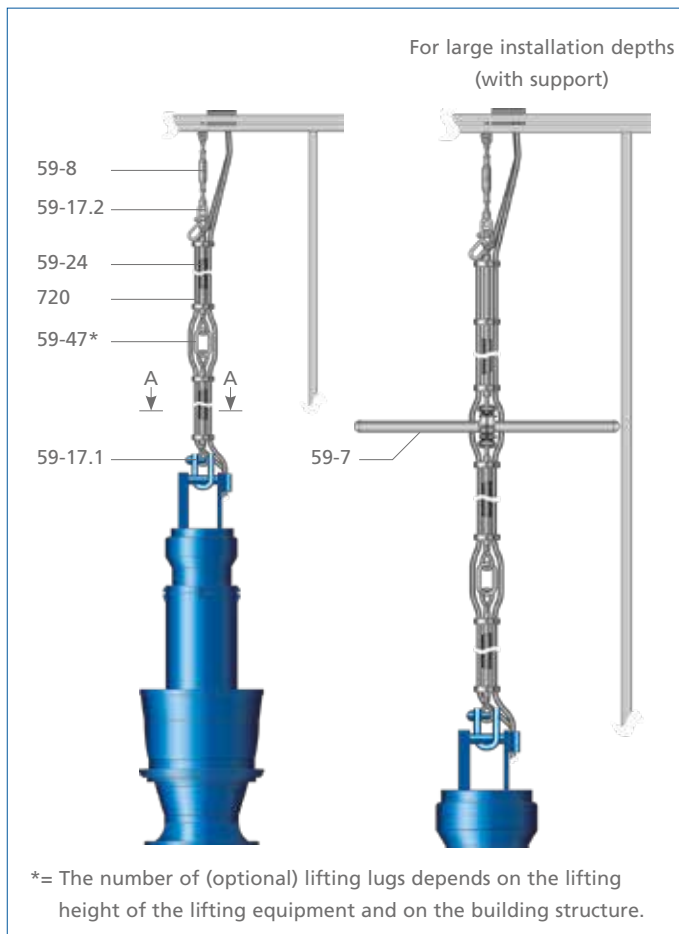


Fig. 87: Support rope and turnbuckle in the discharge tube

List of components

Part No.	Description
1	Clamp
2	Control cable
3	Power cable
4	Support rope 59-24
5	Fitting
6	Clamp cover

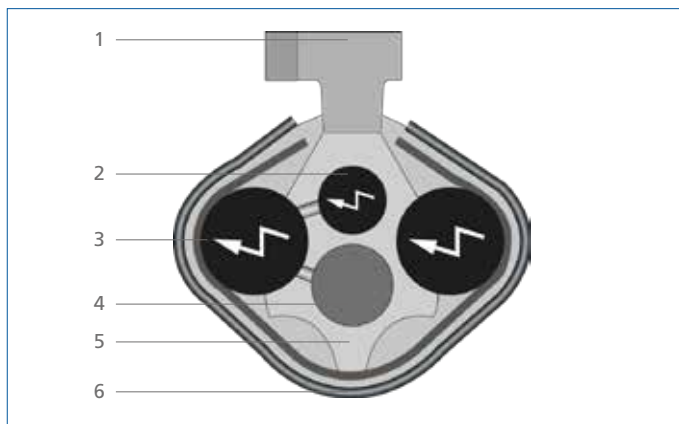


Fig. 88: Cross-section of cable support



# References

- [1] Dr.-Ing. K. Holtzenberger, KSB AG, Centrifugal Pump Design, 5th edition 2005, ISBN 3-00-004734-4
- [2] KSB AG, Amacan P type series booklet, 1580.5/5
- [3] KSB AG, Amacan S type series booklet, 1589.5/5
- [4] KSB AG, Amacan K type series booklet, 1579.5/3
- [5] Hydraulic Institute, American National Standard for Pump Intake Design, ANSI / HI 9.8-1998
- [6] M. J. Prosser, The Hydraulic Design of Pump Sumps and Intakes, BHRA, July 1997
- [7] Henry T. Falvey, Air-Water Flow in Hydraulic Structures, Engineering and Research Center Denver, Colorado 80225, December 1980
- [8] Jost Knauss, Swirling Flow Problems at Intakes, IAHR+AIRH, ISBN 90 6191 643 7, Rotterdam 1987
- [9] Christian Frey, Peer Springer, Dr. Sven Baumgarten, Bernd Kothe, Optimisation of Waste Water Pumping Station Architecture Using CFD Analysis, Validated by Model Testing, Pump Users International Forum 2004, Section 5: Pumps for Waste Water, Karlsruhe, Germany
- [10] Willi H. Hager, Waste Water Hydraulics: Theory and Practice, Springer Verlag, ISBN 3-540-55347-9, 2<sup>nd</sup> Edition, 2010
- [11] I.E. Idelchik, Handbook of Hydraulic Resistance, 3<sup>rd</sup> Edition, Research Institute for Gas Purification, Moscow 1994, ISBN 0-8493-9908-4
- [12] Swiss standard SN CR 13930: Rotodynamic Pumps – Design of Pump Intakes – Recommendations for the Installation of Pumps, VSM 2000
- [13] Charles E. Sweeney, Rex A. Elder, Duncan Hay, Pump Sump Design Experience: Summary, March 1982
- [14] US Army Corps of Engineers, Pumping Station Inflow – Discharge Hydraulics, Generalized Pump Sump Research Study, Technical Report HL-88-2
- [15] Robert Sanks, Pumping Station Design, 2<sup>nd</sup> Edition, Butterworth Heinemann, Boston · Oxford · Johannesburg · Melbourne · New Delhi · Singapore
- [16] P. Tillack, D.-H. Hellmann, A. R uth, Description of Surface Vortices with Regard to Common Design Criteria of Intake Chambers, 2<sup>nd</sup> International Conference on Pumps and Fans, Beijing, China 1995

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## Author

Dipl.-Ing. Bernd Kothe, born in 1955, studied at the Otto von Guericke Technical University in Magdeburg. After completing his studies, he became a development engineer for power station pumps at the Pumpenwerke Halle (Saale) company. From 1993 to 1998 he was responsible for transient flow analysis and complex waste water calculations in the engineering department of KSB AG. Since 2002 he has been working for Technical Sales Support in Halle (Saale), Germany.





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