ANSI/HI 9.8-2012

American National Standard for

Rotodynamic Pumps

for Pump Intake Design

ANSI/HI 9.8-2012

Hydraulic Institute

6 Campus Drive
First Floor North
Parsippany, New Jersey
07054-4406
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American National Standards Institute, Inc.

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Foreword (Not part of Standard)

Purpose and aims of the Hydraulic Institute

The purpose and aims of the Institute are to promote the continued growth of pump knowledge for the interest of pump manufacturers and to further the interests of the public in such matters as are involved in manufacturing, engineering, distribution, safety, transportation and other problems of the industry, and to this end, among other things:

a) To develop and publish standards for pumps;

b) To collect and disseminate information of value to its members and to the public;

c) To appear for its members before governmental departments and agencies and other bodies in regard to matters affecting the industry;

d) To increase the amount and to improve the quality of pump service to the public;

e) To support educational and research activities;

f) To promote the business interests of its members but not to engage in business of the kind ordinarily carried on for profit or to perform particular services for its members or individual persons as distinguished from activities to improve the business conditions and lawful interests of all of its members.

Purpose of Standards

1) Hydraulic Institute Standards are adopted in the public interest and are designed to help eliminate misunderstandings between the manufacturer, the purchaser and/or the user and to assist the purchaser in selecting and obtaining the proper product for a particular need.

2) Use of Hydraulic Institute Standards is completely voluntary. Existence of Hydraulic Institute Standards does not in any respect preclude a member from manufacturing or selling products not conforming to the Standards.

Definition of a Standard of the Hydraulic Institute

Quoting from Article XV, Standards, of the By-Laws of the Institute, Section B:

"An Institute Standard defines the product, material, process or procedure with reference to one or more of the following: nomenclature, composition, construction, dimensions, tolerances, safety, operating characteristics, performance, quality, rating, testing and service for which designed."

Comments from users

Comments from users of this standard will be appreciated, to help the Hydraulic Institute prepare even more useful future editions. Questions arising from the content of this standard may be directed to the Technical Director of the Hydraulic Institute. The inquiry will then be directed to the appropriate technical committee for provision of a suitable answer.

If a dispute arises regarding contents of an Institute publication or an answer provided by the Institute to a question such as indicated above, then the point in question shall be sent in writing to the Technical Director of the Hydraulic Institute, who shall initiate the Appeals Process.

Revisions

The Standards of the Hydraulic Institute are subject to constant review, and revisions are undertaken whenever it is found necessary because of new developments and progress in the art. If no revisions are made for five years, the standards are reaffirmed using the ANSI canvass procedure.

Units of measurement

Metric units of measurement are used; and corresponding US customary units appear in brackets. Charts, graphs, and sample calculations are also shown in both metric and US customary units. Since values given in metric units are not exact equivalents to values given in US customary units, it is important that the selected units of measure to be applied be stated in reference to this standard. If no such statement is provided, metric units shall govern.

Consensus for this standard was achieved by use of the Canvass Method

The following organizations, recognized as having an interest in the standardization of centrifugal pumps were contacted prior to the approval of this revision of the standard. Inclusion in this list does not necessarily imply that the organization concurred with the submittal of the proposed standard to ANSI.

A.W. Chesterton Company
Alden Research Laboratory, Inc.
Bechtel Power Corporation
Black & Veatch (B & V)
Brown and Caldwell
Budris Consulting
Clemson Engineering Hydraulics, LLC
DuPont Company
ekwestrel corp
GIW Industries, Inc.
Gorman-Rupp Company
Healy Engineering, Inc.
J.A.S. Solutions Ltd.
John Anspach Consulting
Kemet Inc.
LVVWD - Las Vegas Valley Water District
Mechanical Solutions, Inc.
MWH Americas, Inc.
Northwest Hydraulic Consultants
Patterson Pump Company
Peerless Pump Company
Powell Kugler, Inc.
Pump Design, Development & Diagnostics, LLC
Sanks, Robert
Sulzer Pumps (US) Inc.
Wasserman, Horton
Weir Floway, Inc.
Weir Minerals North America
Whitley Burchett & Associates
Xylem Inc. - Applied Water Systems
Xylem Inc. - Water Solutions

Committee list

Although this standard was processed and approved for submittal to ANSI by the canvass method, a working committee met many times to facilitate its development. At the time the standard was approved, the committee had the following members:

Chair – Jack Claxton, Patterson Pump Company

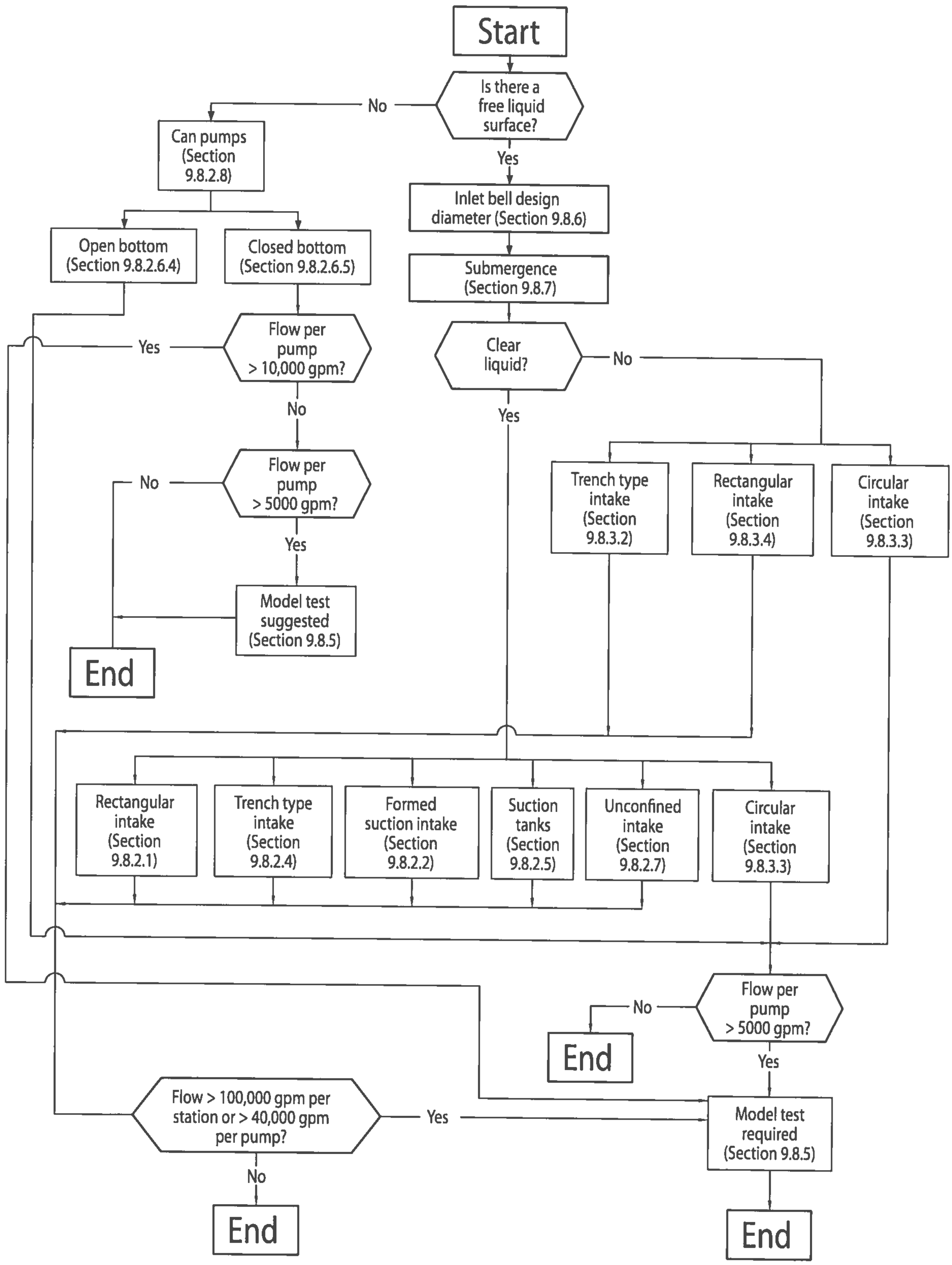
Committee Member	Company
Stefan Abelin	Xylem Inc. - Water Solutions
Tom Angle	Hidrostal
John Anspach	John Anspach Consulting
Bill Beekman	Consultant
Al Behring	MWH Americas, Inc.
Michael Cugal	Weir Minerals
Michael D'Ambrosia	Retired
Thomas Demlow	Northwest Hydraulic Consultants
Randal Ferman	ekwestrel corp
Peter Garvin	Bechtel Corporation
James Healy	Healy Engineering, Inc.
Thomas Hendrey	Whitley Burchett & Associates
Michael Hiscock	South Florida Water Management Dist.
Andrew Johansson	Alden Research Laboratory, Inc.
Garr Jones	Brown and Caldwell
Dimitar Kalchev	Peerless Pump Company
Mika Kaplan	King County
Yuri Khazanov	InCheck Technologies Inc.

Committee Member (continued)	Company (continued)
Robert Krebs	Krebs Consulting Service
Zan Kugler	Powell Kugler, Inc.
Frederick Locher	Bechtel Corporation
Patrick Moyer	Weir Specialty Pumps
Richard O'Donnell	Xylem Inc. - Water Solutions
Mizan Rashid	ENSR
James Roberts	Xylem Inc. - Applied Water Systems
Robert Rollings	DuPont Company
Robert Sanks	Montana State University
Arnold Sdano	Pentair
Tino Senon	MWH
Theodore Stolinski	Black & Veatch (B & V)
Ernest Sturtz	CDM Smith
James Torony	Sulzer Process Pumps
Greg Towsley	Grundfos North America

Alternates	Company
Charlie Allaben	Allaben Consulting
Ed Allis	Retired
Lech Bobowski	Peerless Pump Company
Zbigniew Czarnota	ITT Flygt
George Hecker	Alden Research Laboratory, Inc.

Flowchart For Use Of Standard

NOTE: This flowchart is intended as a guide to the use of this standard and can be used to locate the appropriate sections in this standard. The chart is not a substitute for the understanding of the complete standard.



9.8 Pump intake design

This standard applies to the design of new intakes as well as the modification of existing designs.

In the application of this standard, the pump rated flow shall be used as the design flow for the basis of the intake design. However, other considerations in the installation design and contemplated modes of operation may require the pumps to function under higher rates of flow. In such instances, the maximum rate of flow shall be used for the purposes of pump intake design. Refer to Appendix K for a discussion of this topic.

Note: In applications where piping is used to connect the intake to the pump, ANSI/HI 9.6.6 *Rotodynamic Pumps for Pump Piping* is intended to complement this standard.

9.8.1 Design objectives

Specific hydraulic phenomena have been identified that can adversely affect the performance of pumps. Phenomena that must not be present to an excessive degree are:

- Submerged vortices
- Free surface vortices
- Preswirl magnitude and fluctuation with time
- Nonuniform distribution of velocity in space and time at the impeller eye
- Entrained air or gas bubbles

Ideally, the flow of liquid into any pump should be uniform, steady, and free from swirl and entrained air. Lack of uniformity can cause the pump to operate away from the optimum design condition, and at a lower hydraulic efficiency. Unsteady flow causes the load on the impeller to fluctuate, which can lead to noise, vibration, bearing problems, and fatigue failures of pump shafts.

Swirl in the pump intake can cause a significant change in the operating conditions for a pump, and can produce changes in the flow capacity, power requirements, and efficiency. It can also result in local vortex-type pressure reductions that induce air cores extending into the pump. This and any other air ingestion can cause reductions in pump flow and fluctuations of impeller load that result in noise and vibration, which may lead to physical damage.

The negative impact of each of these phenomena on pump performance depends on pump specific speed and size, as well as other design features of the pump that are specific to a given pump manufacturer. In general, larger pumps and axial flow pumps (high specific speed) are more sensitive to adverse flow phenomena than smaller pumps or radial flow pumps (low specific speed). A more quantitative assessment of which pump types may be expected to withstand a given level of adverse phenomena with no ill effects has not been performed.

The intake structure should be designed to allow the pumps to achieve their optimum hydraulic performance for all operating conditions. A good design ensures that the adverse flow phenomena described above are within the limits outlined in Section 9.8.4.7.

In designing an intake structure, the following points must be considered:

- Flow from the forebay should be directed toward the pump inlets in such a way that the flow reaches the inlets with a minimum of swirl.
- To prevent the formation of air-entraining surface vortices in the sump, the walls must be designed to avoid stagnation regions in the flow. A properly placed wall close to the inlet can reduce the tendency toward localized swirl and vortex formation. The liquid depth also must be great enough to suppress surface vortices.

- Although excessive turbulence or large eddies should be avoided, some turbulence does help to prevent the formation and growth of vortices.

- Station inflow may approach the wet well at a relatively high elevation. In such cases, the liquid may fall a significant distance as it enters the sump. Such a drop can also occur whenever the pumps have lowered the liquid level in the sump to the point at which all pumps are about to be switched off. Therefore, the path between the sump entrance and the pump inlets must be sufficiently long for the air bubbles to rise to the surface and escape before reaching the pumps. The energy of the falling liquid should be dissipated sufficiently so that excessively high and irregular velocities do not occur within the sump. This can be accomplished with properly designed and placed baffle walls.

- The sump should be as small and as simple as feasible to minimize construction costs. However, the required sump volume may be specified for other reasons, such as to provide for a minimum or maximum retention time.

Additional criteria for solids-bearing liquids are covered in Section 9.8.3.

If an intake is designed to a geometry other than that presented in this standard, and this design is shown by prototype testing or a physical model study performed in accordance with Section 9.8.4 to meet the acceptance criteria in Section 9.8.4.7, then this alternative design shall be deemed to comply with this standard.

NOTES:

1) For intake designs where piping is used to connect the intake to the pump, the piping shall comply with ANSI/HI 9.6.6 *Rotodynamic Pumps for Pump Piping*, but model study of piping is covered herein.

2) For intake designs for pumps used for pumping and/or transporting mixtures of solids and liquids or so-called "slurries," refer to ANSI/HI 12.1-12.6 *Rotodynamic (Centrifugal) Slurry Pumps* and the pump manufacturer for guidance.

9.8.2 Intake structures for clear liquids

9.8.2.1 Rectangular intakes

This section is applicable to intake designs for both wet-pit and dry-pit pumps where an intake structure with a free liquid surface exists. Pipeline intakes (no free liquid surface) for dry-pit pumps are covered under ANSI/HI 9.6.6 *Rotodynamic Pumps for Pump Piping*.

9.8.2.1.1 Approach flow patterns

The characteristics of the flow approaching an intake structure are among the most critical considerations for the designer. When determining direction and distribution of flow at the entrance to a pump intake structure, the following must be considered:

- The orientation of the structure relative to the body of supply liquid

- Whether the structure is recessed from, flush with, or protrudes beyond the boundaries of the body of supply liquid

- Strength of currents in the body of supply liquid perpendicular to the direction of approach to the pumps

- The number of pumps required and their anticipated operating combinations

The ideal conditions, and the assumptions on which the geometry and dimensions recommended for rectangular intake structures are based, are that the structure draws flow so that there are no cross-flows in the vicinity of the intake structure that create asymmetric flow patterns approaching any of the pumps, and the structure is oriented so that the supply boundary is symmetrical with respect to the centerline of the structure. As a general guide, cross-flow velocities are significant if they exceed 50% of the pump bay entrance velocity. Section 9.8.4 provides recommendations for analyzing departures from this ideal condition based on a physical hydraulic model study.

9.8.2.1.2 Open versus partitioned structures

If multiple pumps are installed in a single intake structure, then dividing walls placed between the pumps result in more favorable flow conditions than found in open sumps. Adverse flow patterns can frequently occur if dividing walls are not used. For pumps with design flows greater than 315 L/s (5000 gpm), dividing walls between pumps are required.

9.8.2.1.3 Trash racks and screens

Partially clogged trash racks or screens can create severely skewed flow patterns. If the application is such that screens or trash racks are susceptible to clogging, they must be inspected and cleaned as frequently as necessary to prevent adverse effects on flow patterns.

Any screen-support structure that disrupts flow, such as dual-flow traveling screens, otherwise known as *double-entry, single-exit screens* or *single-entry, double-exit screens* can create high-velocity jets and severe instability near the pumps. A physical hydraulic model study must be performed in every such case. The screen exit should be placed a minimum distance of six bell diameters, 6*D*, (see Section 9.8.5) from the pumps. However, this distance should be used only as a general guideline for initial layouts of structures, with final design developed with the aid of a physical model study.

The recommendations in this standard should be followed even if suction bell strainers are used.

9.8.2.1.4 Recommendations for dimensioning rectangular intake structures

The basic design requirements for satisfactory hydraulic performance of rectangular intake structures include the following:

- Adequate depth of flow to limit velocities in the pump bays and reduce the potential for formulation of surface vortices
- Adequate pump bay width, in conjunction with the depth, to limit the maximum pump approach velocities to 0.5 m/s (1.5 ft/s), but narrow and long enough to channel flow uniformly toward the pumps

The minimum submergence *S* required to prevent strong air core vortices is based in part on a dimensionless flow parameter, the Froude number, defined as:

$$F_D = \frac{V}{(gD)^{0.5}} \qquad \text{(Eq. 9.8.2.1.4-1)}$$

Where:

F_D = Froude number at *D* (dimensionless)

V = Velocity at suction inlet = Flow/Area, based on *D*

D = Outside diameter of bell or inside diameter of pipe inlet

g = gravitational acceleration

Consistent units must be used for *V*, *D*, and g so that F_D is dimensionless. The minimum submergence *S* shall be calculated from (Hecker, G.E., 1987)

$$S = D(1 + 2.3F_D) \qquad \text{(Eq. 9.8.2.1.4-2)}$$

where the units of S are those used for D. Section 9.8.6 provides further information on the background and development of this relationship.

It is appropriate to specify sump dimensions in multiples of pump bell diameters D (see Section 9.8.5). Basing dimensions on D ensures geometric similarity of hydraulic boundaries and dynamic similarity of flow patterns. There is some variation in bell velocity among pump types and manufacturers. However, variations in bell inlet velocity are of secondary importance to maintaining acceleration of the flow and converging streamlines into the pump bell.

The basic recommended layout for rectangular sumps, dimensioned in units of pump bell diameter D, is shown in Figure 9.8.2.1.4a. This figure applies to any number of adjacent pumps. The dimension variables and their recommended values are defined in Table 9.8.2.1.4a.

Through-flow traveling screens usually do not clog to the point where flow disturbances occur. Therefore, they may be located such that Y is $4D$ or more in dimension. For non-self-cleaning trash racks or stationary screens, the dimension Y shall be increased to a minimum of $5D$. Care must be taken to ensure that clogging does not occur to the extent that large nonuniformities in the pump approach flow will be generated.

The effectiveness of the recommended pump bay dimensions depends on the characteristics of the flow approaching the structure, and on the geometry of hydraulic boundaries in the immediate vicinity of the structure. Section 9.8.2.1.1 provides a discussion of the requirements for satisfactory approach flow.

Negative values of β (the angle of wall divergence) require flow distribution or straightening devices, and should be developed with the aid of a physical hydraulic model study.

Occasionally, it is necessary to increase the bay width W to greater than $2D$ to prevent velocities at the entrance to the pump bays from exceeding 0.5 m/s (1.5 ft/s). Greater bay widths may also result because of the arrangement of mechanical equipment. In these cases, the bay width in the immediate vicinity of the pumps must be decreased to $2D$. The dimension of the filler required to achieve the reduction in bay width is as shown in Figure 9.8.2.1.4b.

For pumps with design flows of 315 L/s (5000 gpm) or less, no partition walls between pumps are required, and the minimum pump spacing shall be $2D$.

Some pump station applications, such as cooling water circulating pumps withdrawing from cooling tower basins, can have relatively shallow depth at the entrance to the intake structure. Designers should ensure that the gravity-driven inflow is not restricted by the entrance condition to the extent that pumping requirements are not met. A consequence could be dewatering of the intake while the pumps are operating.

Liquid depth at the entrance to the structure will be adequate if the following condition is met:

$$H_1 \geq C\left(\frac{Q}{W_1}\right)^{0.667} \qquad \text{(Eq. 9.8.2.1.4-3)}$$

Where:

Q = total flow at W_1, in L/s (ft^3/s)

H_1 = liquid depth at the entrance to the intake structure, in m (ft)

W_1 = width at the entrance to the intake structure, in m (ft)

C = 0.01 if flow is in L/s and lengths are in m

C = 0.7 if flow is in ft^3/s and lengths are in ft

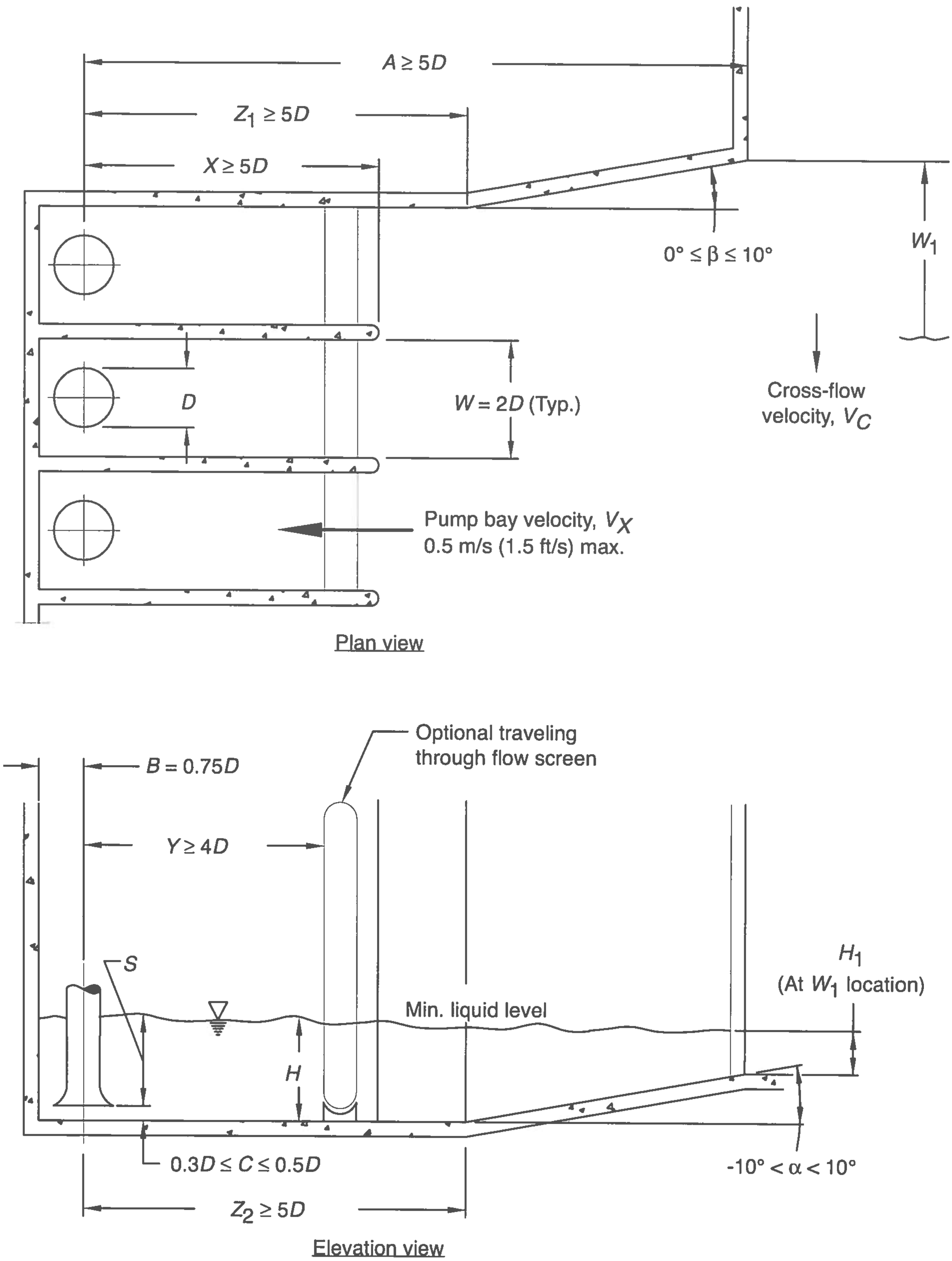


Figure 9.8.2.1.4a — Rectangular intake structure layout

Table 9.8.2.1.4b provides a sequence of steps to follow in determining the general layout and internal geometry of a rectangular intake structure.

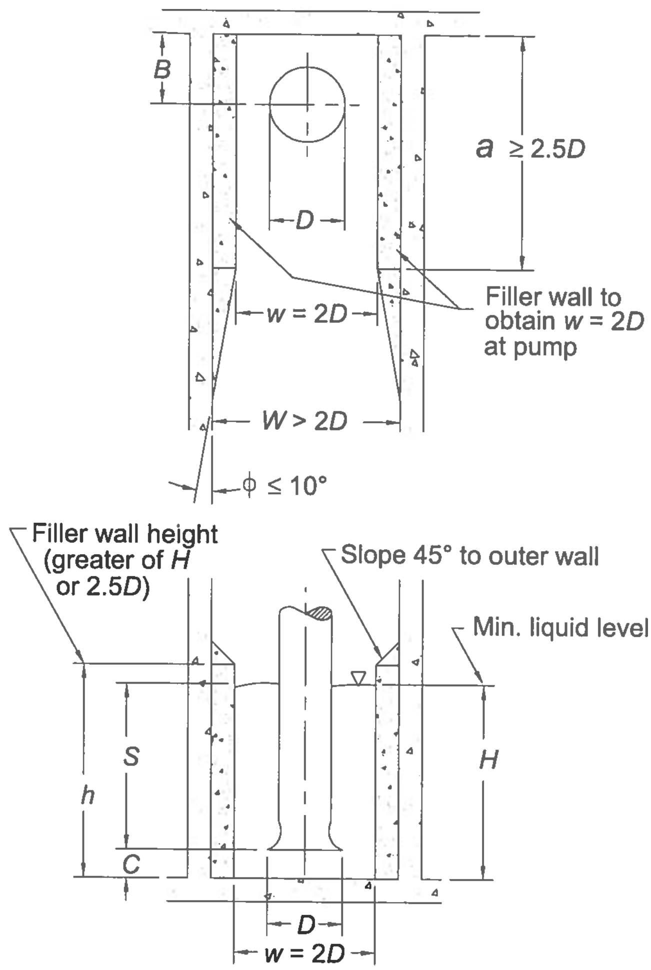


Figure 9.8.2.1.4b — Filler wall details for proper bay width

Table 9.8.2.1.4a — Dimensions for Figures 9.8.2.1.4**a and b**

Dimension Variable	Description	Recommended Value
A	Distance from the pump inlet bell centerline to the intake structure entrance.	$A = 5D$ minimum, assuming no significant cross-flow[a] at the entrance to the intake structure and assuming through flow screens are used
a	Length of constricted bay section near the pump inlet.	$a = 2.5D$ minimum
B	Distance from the backwall to the pump inlet bell centerline.	$B = 0.75D$
C	Distance between the inlet bell and floor.	$C = 0.3D$ to $0.5D$
D	Inlet bell design outside diameter.	See Section 9.8.5.

Table 9.8.2.1.4a — Dimensions for Figures 9.8.2.1.4a **and b (*continued*)**

Dimension Variable	Description	Recommended Value
H	Minimum liquid depth.	$H = S + C$
H_1	Liquid depth at the entrance to the intake structure.	Refer to Eq. 9.8.2.1.4-3.
H_2	Liquid depth just before the basin floor intermediate step boundary. Refer to Figure J.1.	Refer to Eq. J.2-1, substituting H_2 for H_1, substituting the boundary length of the intermediate step for W, and using the total station flow as Q.
h	Minimum height of constricted bay section near the pump inlet bell.	h = (Greater of H or $2.5D$)
S	Minimum pump inlet bell submergence.	$S = D(1.0 + 2.3\ F_D)$. (See Section 9.8.6 for detailed discussion on determining minimum submergence.)
W	Pump bay entrance width.	$W = 2D$ minimum
W_1	Width at the entrance to the intake structure.	Refer to Figure J.1.
w	Constricted bay width near the pump inlet bell.	$w = 2D$
X	Pump inlet bay length.	$X = 5D$ minimum, assuming no significant cross-flow at the entrance to the intake structure and assuming through flow screens are used
Y	Distance from pump inlet bell centerline to the downstream face of through-flow traveling screen.	$Y = 4D$ minimum. Dual-flow screens require a physical model study.
Z_1	Distance from pump inlet bell centerline to diverging walls.	$Z_1 = 5D$ minimum, assuming no significant cross-flow[a] at the entrance to the intake structure.
Z_2	Distance from inlet bell centerline to sloping floor.	$Z_2 = 5D$ minimum
α	Angle of floor slope.	$\alpha = -10$ to $+10$ degrees
β	Angle of wall convergence.	$\beta = 0$ to $+10$ degrees. (Negative values of β, if used, require flow distribution devices developed through a physical model study.)
ϕ	Angle of convergence from constricted area to bay walls.	$\phi = 10$ degrees maximum

[a]Cross-flow is considered significant when $V_C > 0.5\ V_X$ average (see Figure 9.8.2.1.4a).

Table 9.8.2.1.4b — Design sequence, rectangular intake structures

Design Step	Description
1	Consider the flow patterns and boundary geometry of the body of liquid from which the pump station is to receive flow. Compare with the approach flow condition described in Section 9.8.2.1.1 and determine from Section 9.8.4.1 if a hydraulic physical model study is required.
2	Determine the number and size of pumps required to satisfy the range of operating conditions likely to be encountered.
3	Identify pump inlet bell diameter. If final bell diameter is not available, use the relationship in Figures 9.8.5.2a and b to obtain the inlet bell design diameter.
4	Determine the bell-floor clearance, see Figure 9.8.2.1.4a and b. A good preliminary design number is 0.5*D*.
5	Determine the required bell submergence, using the relationship in Section 9.8.6.
6	Determine the minimum allowable liquid depth in the intake structure from the sum of the floor clearance and the required bell submergence.
7	Check bottom elevation near the entrance to the structure and determine if it is necessary to slope the floor upstream of the bay entrance. If the resulting depth at the entrance to the intake structure is shallow, then check to ensure that gravity-driven flow is not restricted by the entrance condition.
8	Check the pump bay velocity for the maximum single-pump flow and minimum liquid depth with the bay width set to 2*D*. If bay velocity exceeds 0.5 m/s (1.5 ft/s), then increase the bay width to reduce to a maximum flow velocity of 0.5 m/s (1.5 ft/s).
9	If it is necessary to increase the pump bay width to greater than 2*D*, then decrease bay width in the vicinity of the pumps according to Figure 9.8.2.1.4b.
10	Compare cross-flow velocity (at maximum system flow) to average pump bay velocity. If cross-flow value exceeds 50% of the bay velocity, a physical hydraulic model study is necessary.
11	Determine the length of the structure and dividing walls, giving consideration to minimum allowable distances to a sloping floor, screening equipment, and length of dividing walls. If dual flow traveling screens or drum screens are to be used, a physical hydraulic model study is required (see Section 9.8.4.1).
12	If the final selected pump bell diameter and inlet velocity is within the range given in Section 9.8.5, then the sump dimensions (developed based on the inlet bell design diameter) need not be changed and will comply with these standards.

9.8.2.2 Formed suction intakes

9.8.2.2.1 General

This portion of the standard applies to formed suction intakes (FSI). The standard uses an FSI adapted from the "TYPE 10" design developed by the US Army Corps of Engineers (ETL No. 110-2-327). The formed suction intake may eliminate the need for the design of sumps with approach channels and appurtenances to provide satisfactory flow to a pump. The recommended FSI design is relatively insensitive to the direction of approach flow and skewed velocity distribution at its entrance. In applying the FSI design, consideration should be given to the head loss in the FSI that will affect to some extent the system curve calculations, and the NPSH available to the pump impeller, typically located near the FSI exit.

9.8.2.2.2 Recommended dimensions for FSI

The recommended FSI design dimensions are indicated in Figure 9.8.2.2.2. The wall shown in Figure 9.8.2.2.2 above the FSI opening reduces the tendency for surface vortices when the FSIs are installed in individual bays. The wall is not necessary for unrestricted approach flow conditions. To minimize flow separation at the FSI intake, the indicated radii at the vertical and sidewalls are recommended. Consult pump manufacturer for assistance in determining *d*.

9.8.2.2.3 Application standards

Minimum submergence (see Section 9.8.6) is calculated as follows:

$$\frac{S}{D_e} = 1.0 + 2.3F_D \qquad \text{(Eq. 9.8.2.2.3-1)}$$

Where:

S = The distance from the minimum recommended liquid level to the centerline of the FSI opening in the elevation view

D_e = The diameter of a circle having an area equivalent to the rectangular FSI opening, $D_e = \left[\left(\frac{4}{\pi}\right) W H_f\right]^{0.5}$

V (used in F_D) = The average velocity through the FSI opening

9.8.2.2.4 Alternative FSI designs

Alternative FSI designs are shown in Appendix I, for reference. At the time of publication of this standard, sufficient data pertaining to these designs were not available to an extent that would allow this material to be considered Hydraulic Institute standard designs. Alternative FSI designs can be utilized if they comply with criteria given in Section 9.8.4.7.

9.8.2.3 Circular pump stations (clear liquids)

9.8.2.3.1 General

A circular design is suitable for many types and sizes of pump stations, see Figures 9.8.2.3.1a through f. It can be used with most types of pumps and for most types of liquids. A circular design may offer a more compact layout that often results in reduced construction costs.

The circular geometry results in a smaller circumference, and hence minimizes excavation and construction materials for a given sump volume. The circular geometry lends itself to the use of the caisson construction technique. The availability of prefabricated circular construction elements has made this design the most popular for smaller pump stations. Fully equipped prefabricated pump stations often have a circular design for the above reasons.

The recommended designs of circular stations are categorized in two groups: duplex and triplex. Stations with four or more pumps are not addressed in this standard because of complex flow patterns; such designs require a physical model study. Circular pump sumps for flows exceeding 315 L/s (5000 gpm) per pump require a physical model study. Circular pump sumps per Figures 9.8.2.3.1c and 9.8.2.3.1f with station flows exceeding 315 L/s (5000 gpm) require a physical model study.

The designs shown in this section are based on one pump being an installed spare.

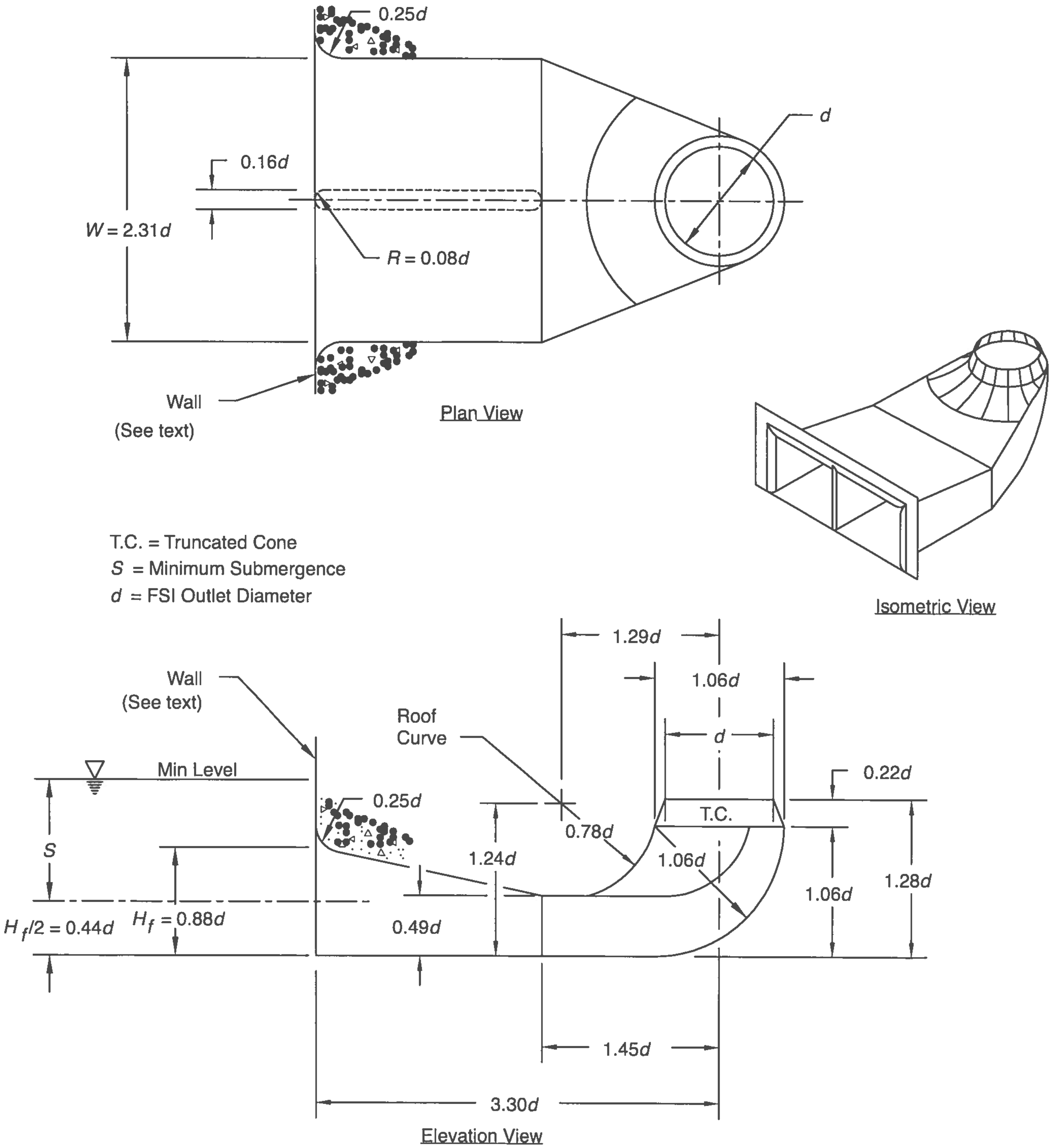
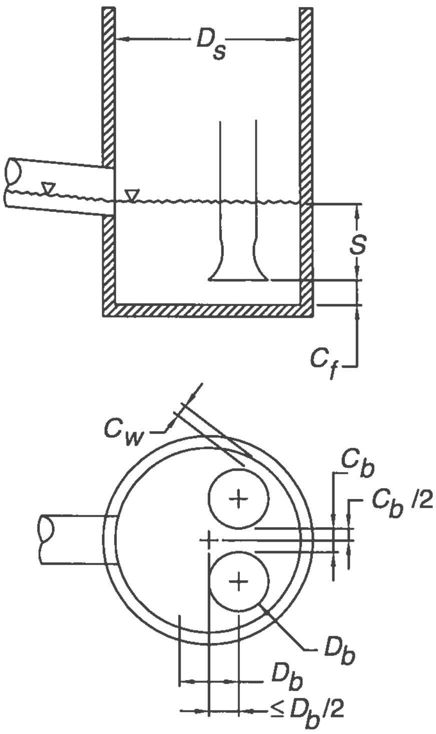
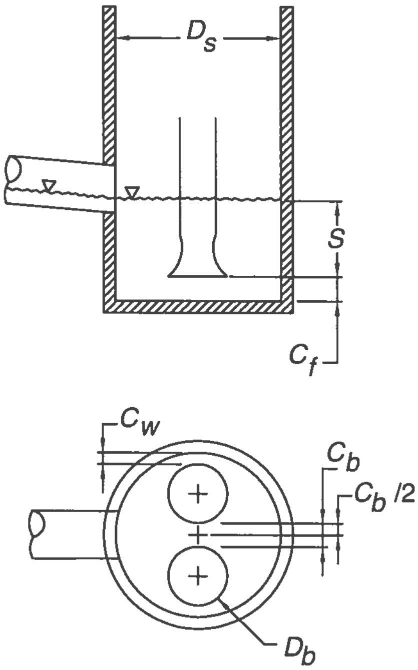


Figure 9.8.2.2.2 — Formed suction intake



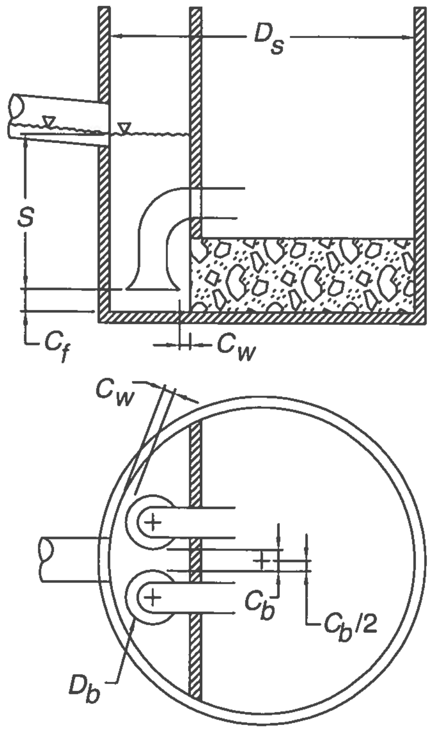
$D_{s\,min} = 2.5\ D_b + 2\ C_w + C_b$

Figure 9.8.2.3.1a — Wet-pit duplex sump with pumps offset



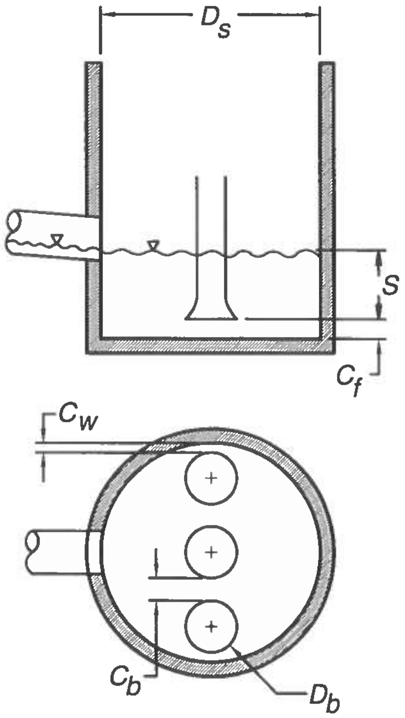
$D_{s\,min} = 2D_b + 2C_w + C_b$

Figure 9.8.2.3.1b — Wet-pit duplex sump with pumps on centerline



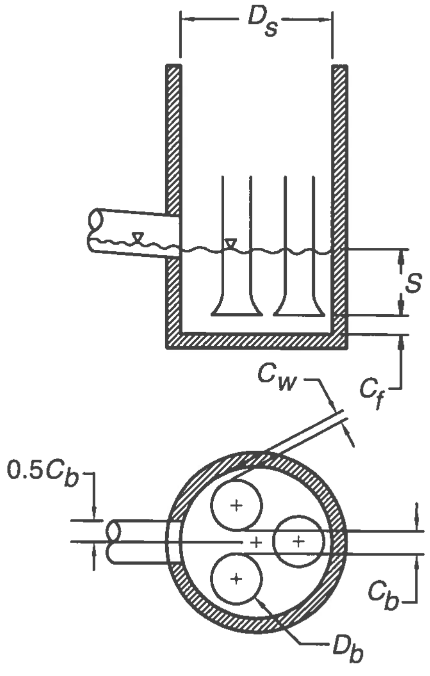
D_s by pit design

Figure 9.8.2.3.1c — Dry-pit/wet-pit duplex sump



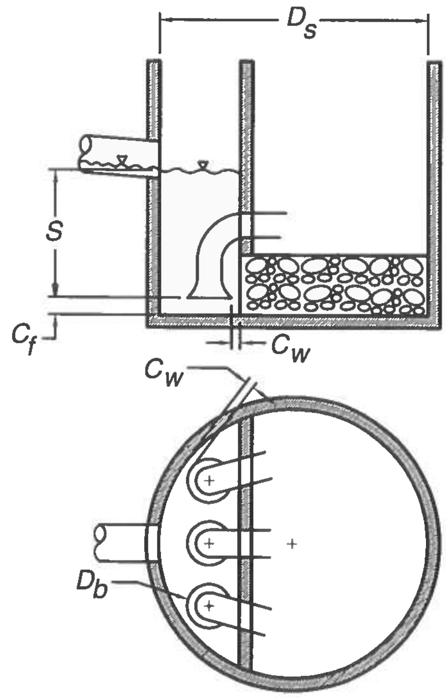
$D_{s\,min} = 3D_b + 2C_w + 2C_b$

Figure 9.8.2.3.1d — Wet-pit triplex sump, pumps in line



$D_{s_{min}} = 2C_w + D_b + C_b\ \mathrm{Sin}\ (60°)$

Figure 9.8.2.3.1e — Wet-pit triplex sump, compact



D_s by pit design

Figure 9.8.2.3.1f — Dry-pit/wet-pit triplex sump

9.8.2.3.2 Recommendations for dimensioning circular pump stations

9.8.2.3.2.1 Nomenclature

C_f = Floor clearance

C_w = Wall clearance

C_b = Inlet bell or volute clearance (as applicable)

D_s = Sump diameter

D_b = Inlet bell or volute diameter (as applicable)

S = Submergence, the vertical distance from minimum sump liquid level to pump inlet, usually pump inlet bell (see Section 9.8.6 for details)

9.8.2.3.2.2 Floor clearance C_f

The floor clearance should not be greater than necessary because excessive floor clearance increases the occurrence of stagnant zones as well as the sump depth at a given submergence. The conditions that determine the minimum floor clearance (C_f) are the risk of increasing inlet head loss and flow separation at the bell. Submerged vortices are also sensitive to floor clearance. Recommended floor clearance is between 0.3 D_b and 0.5 D_b.

9.8.2.3.2.3 Wall clearance C_w

The minimum clearance between an inlet bell or a pump volute and a sump wall is 0.25 D_b or at least 100 mm (4 in).

9.8.2.3.2.4 Inlet bell clearance C_b

The minimum clearance between adjacent inlet bells or volutes (as applicable) is 0.25 D_b or at least 100 mm (4 in).

9.8.2.3.2.5 Sump diameter D_s

Minimum sump diameter shall be as indicated for each type of pump sump as shown in Figures 9.8.2.3.1a through 9.8.2.3.1f.

9.8.2.3.2.6 Inlet bell or volute diameter D_b

This parameter is given by the proposed pump type and model.

For submersible and other pumps with a volute in the wet pit, use the volute diameter. Refer to manufacturer for the volute diameter information.

For pumps without a volute in the wet pit, use the inlet bell diameter.

9.8.2.3.2.7 Inflow pipe

The inflow pipe shall not be placed at an elevation higher than that shown in the figures. This placement minimizes air entrainment for liquid cascading down into the sump from an elevated inflow pipe. It is important to position the inflow pipe(s) radially to the pumps, as shown in the figures, to minimize rotational flow patterns. For the last five pipe diameters before entering the sump, the inflow pipe(s) shall be straight and have no valves or fittings.

Note: High inlet pipe velocity can cause excessive turbulence in this type of wet well. An appropriate inlet pipe velocity has not been determined for this configuration. The designer is cautioned to rely on prior successful experience with a similar wet-well configuration and similar flows.

9.8.2.4 Trench-type intakes (clear liquids)

This section establishes criteria for design of trench-type wet wells using both formed suction and bell-type pump inlets for clear liquid applications.

9.8.2.4.1 General

Trench-type wet wells differ from rectangular intake structures (see Section 9.8.2.1) by the geometry used to form a transition between the dimensions of the influent conduit or channel and the wet well itself. As illustrated in Figures 9.8.2.4.1a and 9.8.2.4.1b, an abrupt transition is used to create a confined trench for the location of the pump inlets.

While only limited physical modeling work has been conducted on trench-type wet wells, successful applications with individual pump capacities as great as 4730 L/s (75,000 gpm) and installation capacities of 14,200 L/s (225,000 gpm) have been constructed for centrifugal pumps. Axial and mixed flow applications of the trench-type wet well include individual pump capacities of 2900 L/s (46,000 gpm) and total installation capacities of up to 12,000 L/s (190,000 gpm). Most applications of the trench-type design have been with the incoming flow directed along the wet well's long axis (coaxial). Physical model studies shall be conducted for any installation with individual pump capacities exceeding 2520 L/s (40,000 gpm) or stations with capacities greater than 6310 L/s (100,000 gpm).

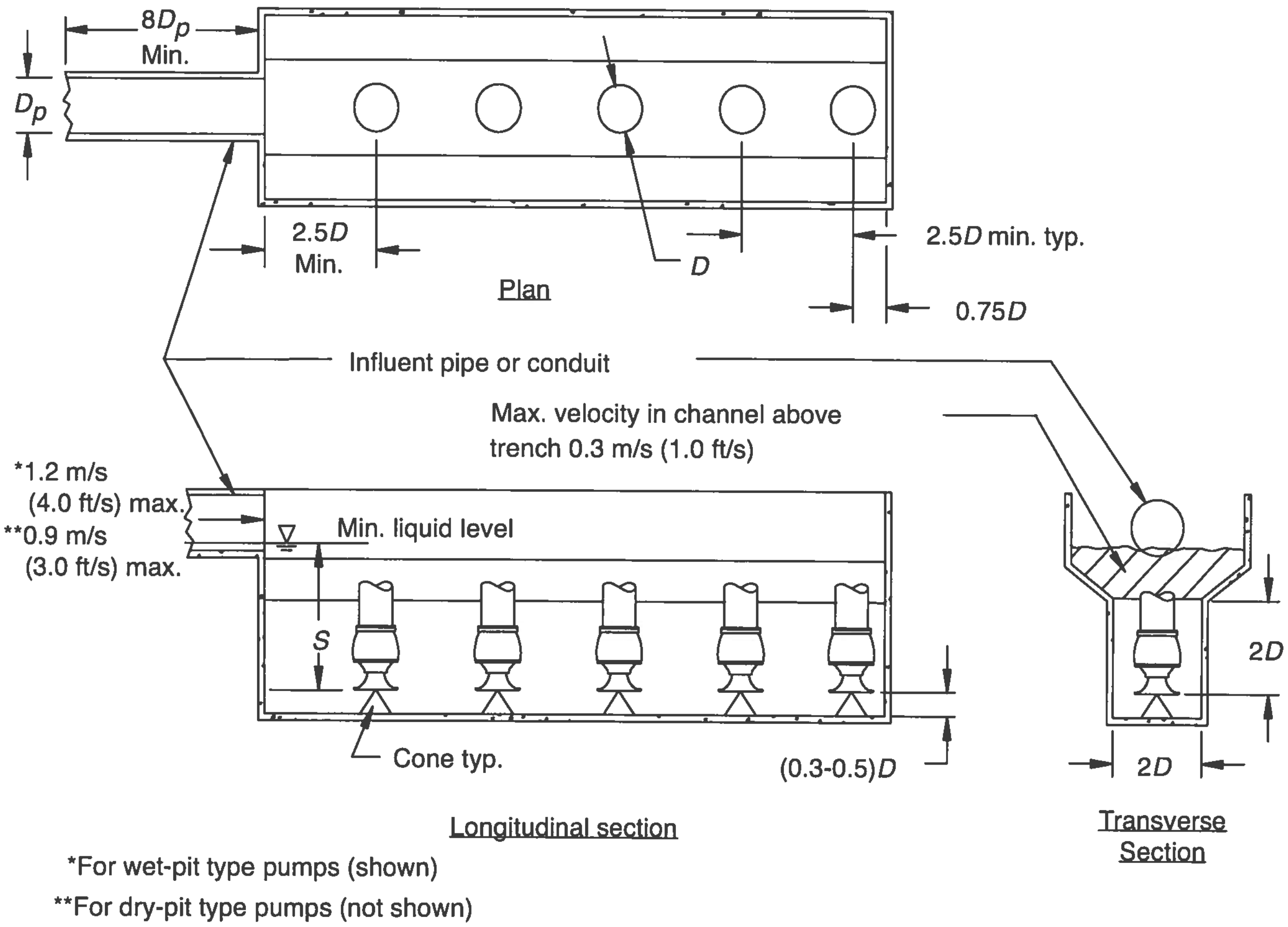


Figure 9.8.2.4.1a — Trench-type wet well

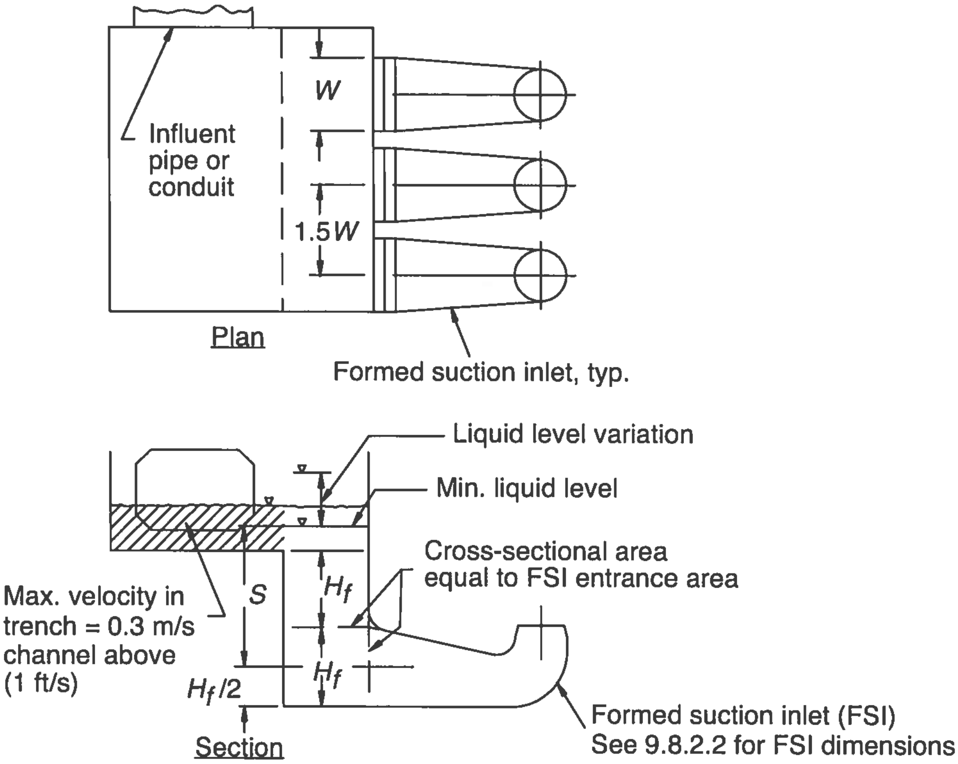


Figure 9.8.2.4.1b — Trench-type wet well with formed suction inlet

9.8.2.4.2 Objectives

The purpose of the trench-type wet well is to shield the pump intakes from the influence of the concentrated inflow. The shielding is accomplished by locating the inlets well below the invert of the influent channel or conduit.

9.8.2.4.3 Orientation

Align the long axis of the wet well with the centerline of the upstream conduit or channel. Offset centerlines are not recommended.

9.8.2.4.4 Approach flow

The velocity in the approach channel or conduit, upstream from the wet well, shall be no greater than:

- 1.2 m/s (4.0 ft/s) with the axis of the channel or conduit coaxial with the axis of the wet well for vertical pumps or submersible pumps
- 0.9 m/s (3.0 ft/s) with the axis of the channel or conduit coaxial with the axis of the wet well for pumps with suction piping extending from the dry well into the wet well

The influent pipe upstream from the trench shall be straight and free of fittings or devices that will disrupt the flow uniformity entering the trench for a distance equal to at least eight times the influent pipe diameter.

9.8.2.4.5 Width

The recommended width of the bottom of the trench for trench-type wet wells is twice the diameter of the pump intake bell. The width of the sump above the trench must be expanded to produce an average limiting velocity in the trapezoidal area above the trench of 0.3 m/s (1.0 ft/s). See Figure 9.8.2.4.1a.

9.8.2.4.6 Intake submergence

See submergence section (Section 9.8.6).

9.8.2.4.7 End wall clearance

Clearance between the centerline of the intake bell and the end walls of the trench should be 0.75*D*.

9.8.2.4.8 Floor clearance

Clearance between the floor of the trench and the rim of the inlet bell shall be 0.3*D* to 0.5*D*. Floor cones are recommended under each of the pump inlet bells. See Section 9.8.3.2.3.2 for solids-bearing liquids.

9.8.2.4.9 Centerline spacing

Centerline spacing of adjacent intake bells shall be no less than 2.5*D*.

9.8.2.4.10 Inlet conduit elevation

The elevation of the incoming conduit shall be adjusted so that a cascade is avoided at the minimum liquid level.

9.8.2.5 Tanks - pump suction

9.8.2.5.1 General

This section applies to partly filled tanks, pressurized or nonpressurized, handling non-solids-bearing liquids where the outflow occurs with or without simultaneous inflow. The following design features are considered:

Tank Geometry

- Vertical Cylindrical
- Horizontal Cylindrical
- Rectangular

Outlet Orientation and Location

- Vertical, Downwards
- Horizontal, Side
- Horizontal, Bottom
- Vertical, Upwards

Outlet Configuration

- Flush With Tank Interior Surface
- Protruding Through Tank Interior Surface

Outlet Fitting

- Straight
- Cone
- Bell

Note: In suction tank applications where piping is used to connect the intake to the pump, the piping shall comply with ANSI/HI 9.6.6 *Rotodynamic Pumps for Pump Piping.*

9.8.2.5.2 Objectives

The purpose of this section is to recommend features of tank connections to minimize air or gas entrainment during the pumping process. It is assumed that the pump is far enough downstream of the tank outlet, such that the requirements of ANSI/HI 9.6.6 govern.

9.8.2.5.3 Discussion

Due to the formation of vortices inside the tank, air or gas entrainment can occur in pump suction tanks, even when the tank outlet is totally submerged. Severe cases of air entrainment can cause erratic or noisy pump operation or reduction in pump performance. A pump is affected by entrained air that can collect, and in severe cases, block the impeller eye and cause loss of prime.

The extent of air entrainment, caused by vortex formation in a suction tank, depends on the vortex strength, submergence of the tank outlet, and the fluid velocity in the tank outlet. Vortices may occur in tanks under vacuum or pressure, whether or not the level is varying or steady due to inflow.

9.8.2.5.4 Submergence

See Figure 9.8.2.5.4, examples 1 through 4. The recommended minimum submergence S of the outlet fitting below the free surface of the liquid within the tank to prevent air core vortices, given tank outlet diameter D, may be obtained from the relationship

$$\frac{S}{D} = 1.0 + 2.3F_D \qquad \text{(Eq. 9.8.2.5.4-1)}$$

Where:

F_D = Froude number = $\dfrac{V}{(gD)^{0.5}}$

D = outlet fitting diameter

V = outlet fitting velocity

g = acceleration of gravity

For further discussion of submergence, see Section 9.8.6.

9.8.2.5.5 Application options

Whereas Figure 9.8.2.5.4, examples 1 through 4, show how the calculated submergence value is to be applied, Figure 9.8.2.5.5, examples 5 through 8, show where values of V and D are obtained for the three types of outlet fitting designs: straight, cone-shaped, and bell-shaped. If the desired minimum submergence is less than that calculated by the above relationship, the outlet size, and therefore fluid velocity, may be adjusted to reduce the required minimum submergence. It may be desirable to use a bell-shaped or cone-shaped fitting to reduce the head loss in the fitting. In such cases, shown in Figure 9.8.2.5.5, examples 5 through 8, the largest diameter of the fitting is used in the above equations to calculate velocity, V. Owing to the uncertain approach conditions typically encountered in a closed tank or vessel, outlet vortex breakers as illustrated in Appendix A, Figure A.13, should be considered.

9.8.2.5.6 NPSH considerations

All the head losses incurred from the free liquid surface to the pump inlet must be considered when calculating the NPSH available for the pump.

9.8.2.5.7 Simultaneous inflow and outflow

In general, tanks should not have the inlet pipe close to the tank outlet when inflow and outflow occur simultaneously. Suitable baffling or other flow distribution devices may be required to isolate the outlet or reduce the inlet effects on flow patterns. Special attention should also be given to the design to avoid air entrainment with a non-submerged inlet pipe.

Guidelines provided in Appendix A.7 may be helpful.

9.8.2.5.8 Multiple inlets or outlets

The design of tanks with multiple inlets and/or outlets should be such that unsatisfactory flow interaction does not occur. Baffling or other flow distribution devices may be required to eliminate such effects.

Guidelines provided in Appendix A.7 may be helpful.

9.8.2.6 Can vertical turbine pump intakes (clear liquids), including those with submersible motors (refer to Appendix G)

9.8.2.6.1 General

A can pump is a pump that has a barrel around the pumping unit.

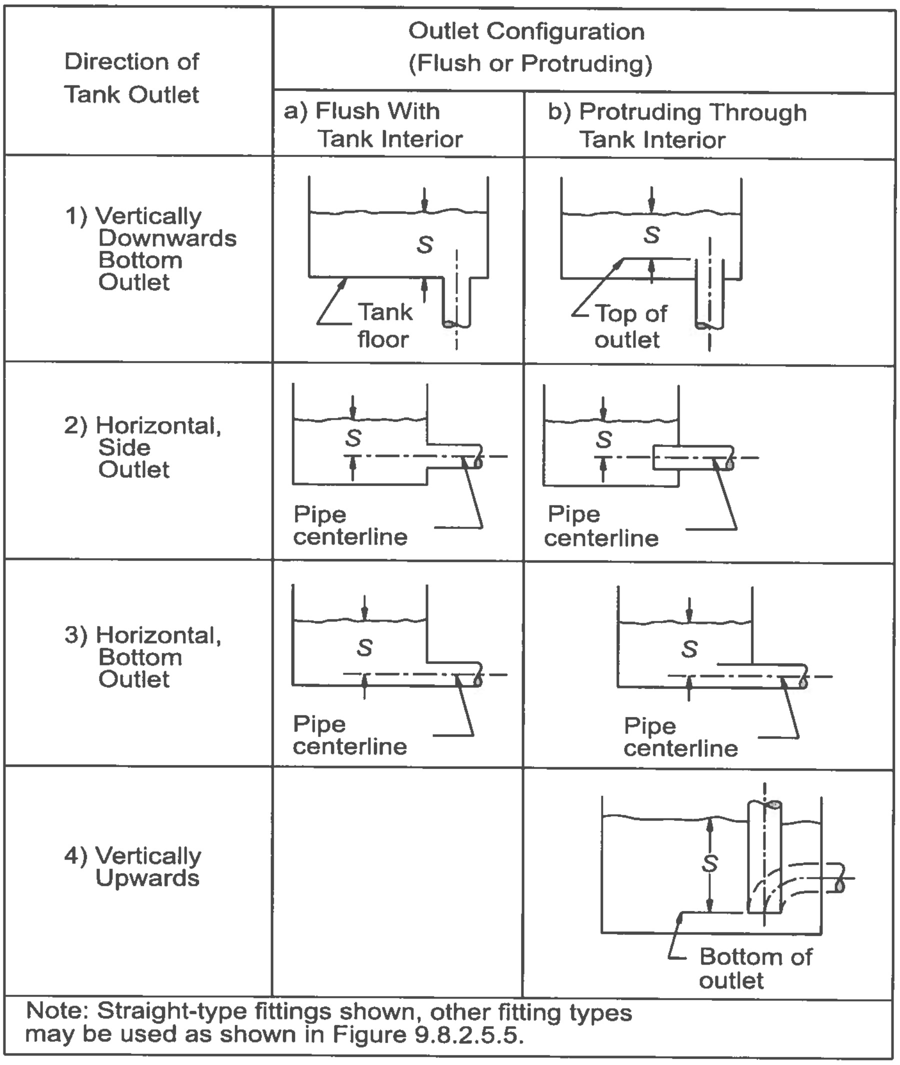


Figure 9.8.2.5.4 — Datum for calculation of submergence

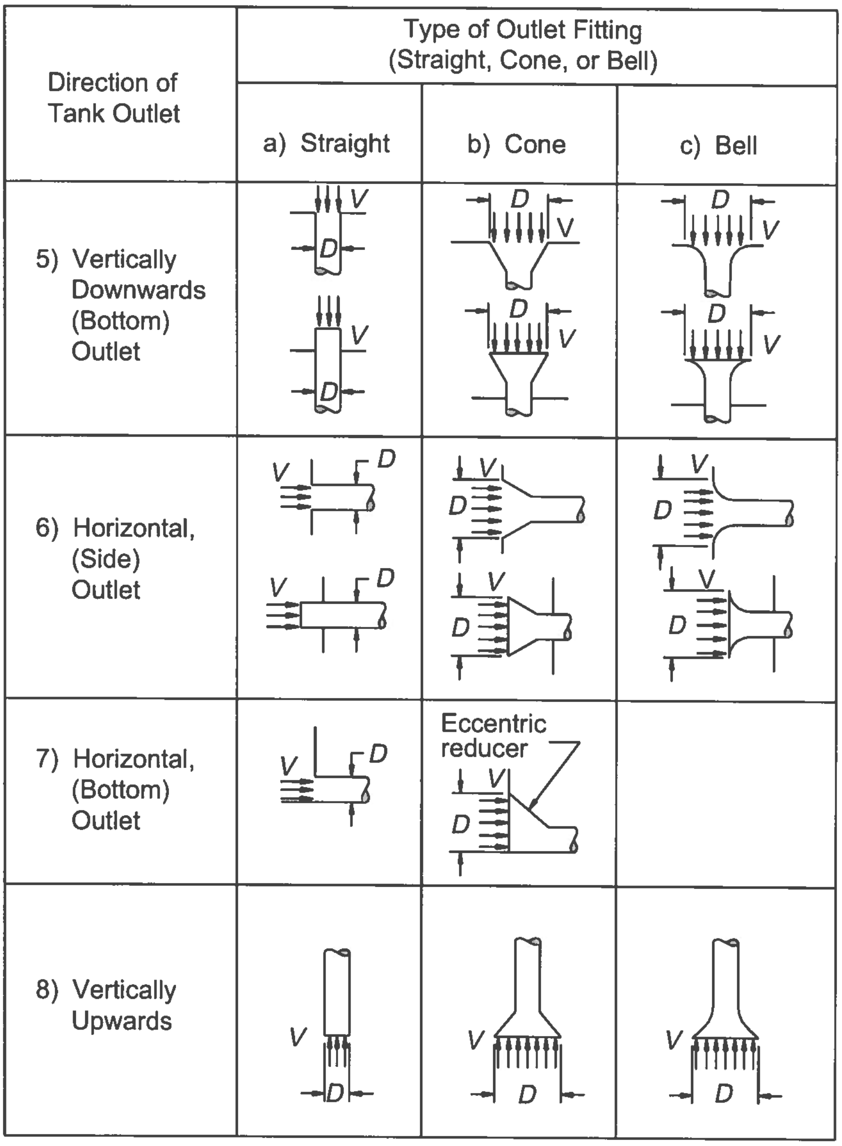


Figure 9.8.2.5.5 — Definitions of *V* and *D* for calculation of submergence

The purpose of this section is to establish criteria for the design of clear liquid intakes for open bottom and closed bottom can vertical turbine pumps as well as for submersible (well motor driven) vertical turbine pumps. It is necessary to avoid designs to simply fit into a piping arrangement without considering flow patterns to the can inlet or in the barrel itself. For submersible vertical turbine pumps, the cooling of the immersed motor must also be considered.

The intake design information provided is for vertical turbine type pumps with specific speed less than 100 (5000 US customary units). Higher specific speed vertical mixed flow and propeller pumps may perform in a barrel; however, they are more sensitive to hydraulic suction design. Refer to the pump manufacturer for specific can intake designs for these pumps.

9.8.2.6.2 Objective

The following provides guidelines to avoid unfavorable flow conditions for both open bottom and closed bottom vertical turbine can pump intakes.

9.8.2.6.3 Design considerations

It is necessary to design the can intake such that the first-stage impeller suction bell inflow velocity profile is uniform. An asymmetrical velocity profile may result in hydraulic disturbances, such as swirling, submerged vortices, and cavitation that may result in performance degradation and accelerated pump wear.

It is recommended that the vertical pump be allowed to hang freely suspended and without restraining attachments to its vertical pump can (riser). However, if it is necessary to install restraining attachments between the pump and barrel, such as for seismic compliance, binding of the pump must be avoided.

The pump manufacturer should be consulted regarding the design of any component that affects the pump hydraulic intake performance. These include the suction barrel, 90-degree turning vane elbow, and vortex suppressor.

9.8.2.6.4 Open bottom can intakes (Figure 9.8.2.6.4)

The minimum liquid level is considered a minimum operational level. When the pump is started, the minimum liquid level will reduce momentarily until the pump flow velocity is achieved. The intake piping must be large enough to limit drawdown below the recommended minimum suction level to a period of less than 3 seconds during start-up.

Open bottom can intakes with flows greater than 315 L/s (5000 gpm) per pump require a physical model study.

Example 1 - This pump intake configuration is particularly effective when liquid elevations (pump submergence) is limited. Flows through a horizontal suction header with velocities up to 2.4 m/s (8.0 ft/s) can be effectively directed into a vertical turbine pump by use of a 90-degree vaned elbow.

The 90-degree turning vane inlet diameter shall be sized to limit the inflow velocity to 1.5 m/s (5.0 ft/s). Attachment of a 90-degree vaned elbow to the horizontal header is recommended to provide hydraulic thrust restraint. Caution is necessary when using this intake configuration in liquids containing trash or crustaceans that attach to the turning vanes.

Example 2 - The vortex suppressor and pump are an integral assembly that can be removed for repair, cleaning, and inspection. A vortex suppressor is necessary to break up abnormal flow patterns ahead of the pump suction bell. For vertical turbine pumps with rated flows less than 315 L/s (5000 gpm) the maximum horizontal header velocity is 1.8 m/s (6.0 ft/s) and the maximum riser velocity is 1.5 m/s (5.0 ft/s). The installation must allow the pump to hang centered in the vertical riser pipe.

Example 3 - When the vertical riser is located at the end of a suction header, a 90-degree vaned elbow must be used to direct flow into the pump's suction. This intake configuration is effective when liquid elevation (pump submergence) is limited. The 90-degree turning vane inlet diameter shall be sized to limit the inflow velocity to 1.5 m/s (5.0 ft/s).

Example 4 - A 90-degree long radius elbow may be used at the end of a suction header to direct flow into the pump suction when velocities are less than 0.6 m/s (2.0 ft/s). Installing vanes in the elbow (although difficult) promotes a uniform velocity flow profile. Velocities up to 1.5 m/s (5.0 ft/s) are acceptable when the elbow is fully vaned.

A flexible joint between the pump suction and the elbow is recommended to isolate the pump from piping loads. Because this is a dry-pit application, the joints throughout the pump should be sealed against leakage by the use of O-rings, gaskets, etc.

9.8.2.6.5 Closed bottom can (Figure 9.8.2.6.5)

The most typical can pump configurations are closed bottom. See Figure 9.8.2.6.5 for design recommendations with various inlet pipe positions relative to the bell. A model test is suggested for closed bottom can intakes for pump flows exceeding 315 L/s (5000 gpm). Closed bottom can intakes for pump flows exceeding 630 L/s (10,000 gpm) require a physical model study.

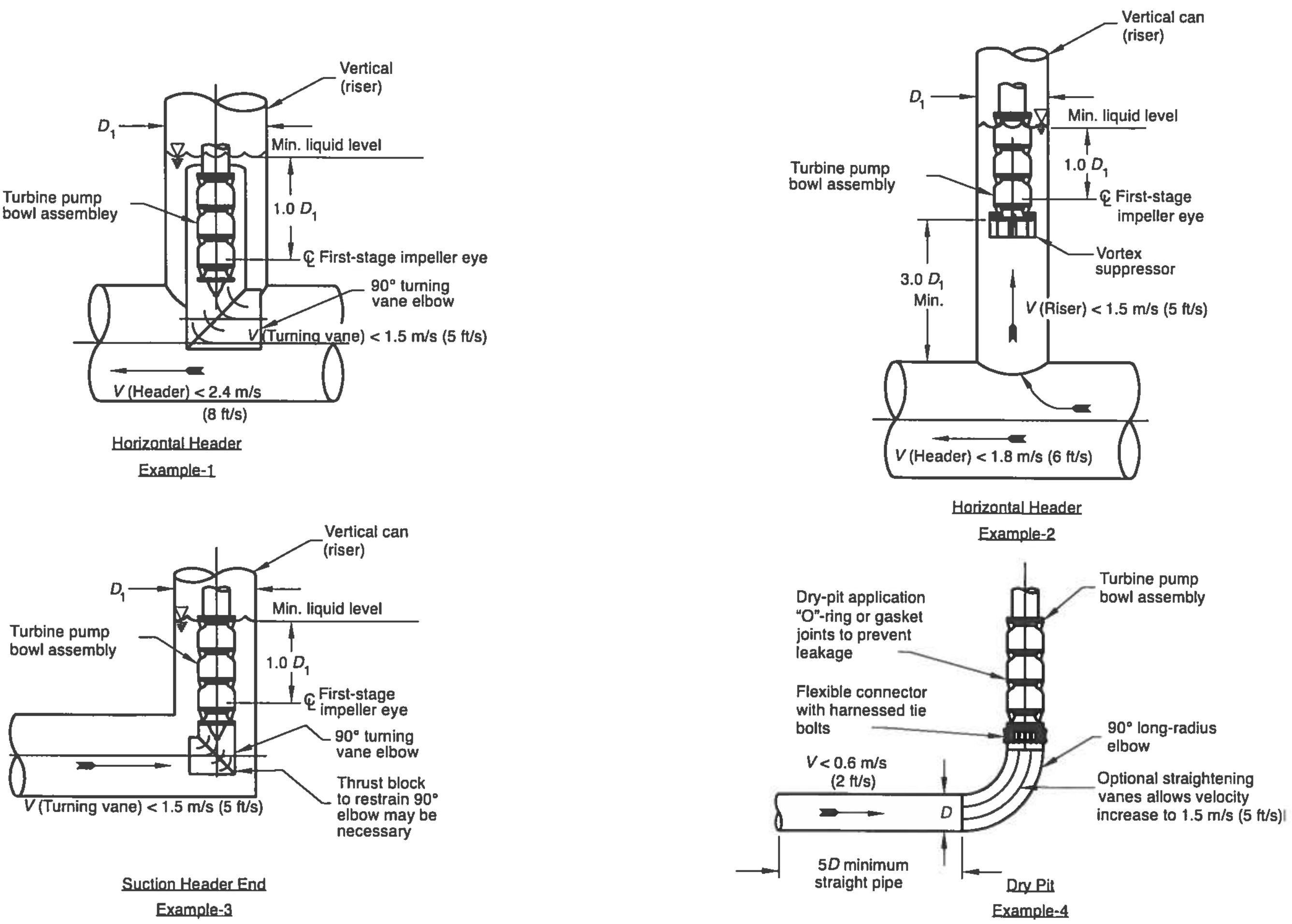


Figure 9.8.2.6.4 — Open bottom can intakes

Centering of the pump in relation to the can to avoid rotational flow being generated by nonuniform flow around a noncentered pump is of particular importance. Care must be taken during installation of the barrel to ensure concentricity of pump to barrel. When cans are grouted in during installation, the buoyancy effect must be addressed to keep the can from "floating" out of level. After installation of the can is complete, the mounting surface of the pumps must be level in all directions within 0.42 mm/m (0.005 in/ft). The bottom of the can shall be plumb to ensure that the suction bell can be centered within 3% of the suction bell diameter (0.03 x *D*).

Flow-straightening vanes are suggested for all can intakes and shall be provided for pump capacities greater than 189 L/s (3000 gpm). A pair of vanes should be centered on the inlet to the barrel and extended to above the normal liquid level or to the top of the barrel, as applicable. The vanes should protrude as far as practical into the barrel while avoiding unintended contact with the bowl or the suction bell. A set of vanes in the form of a cross should be provided under the pump bell. In some applications, the pump manufacturer may wish to use other methods to prevent swirling.

When the addition of vanes to the interior of the can is impractical due to the use of a concrete caisson, or if the suction can has been oversized for the installation of a larger future pump, consideration should be given to the use of a vortex suppressor.

Because of the limited volume provided by a can-type intake, surging of the liquid level within the barrel may be a problem when operating with a partially filled can.

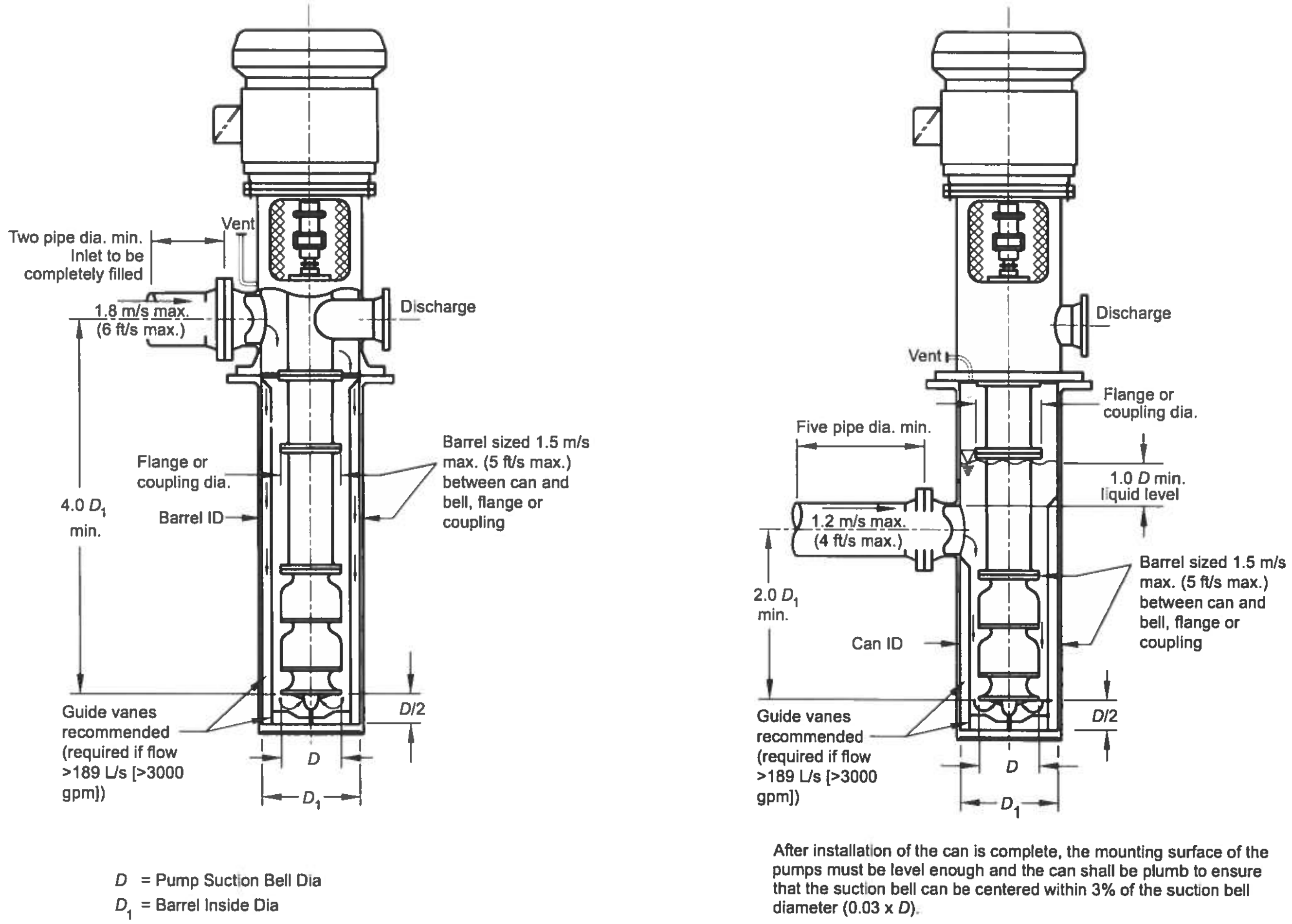


Figure 9.8.2.6.5 — Closed bottom can

The intake piping must be large enough to limit drawdown below the recommended minimum liquid level to a period of less than three seconds during start-up.

Under steady state operation the hydraulic grade line shall allow for a minimum liquid level of 1.0*D* above the crown of the inlet pipe. See Figure 9.8.2.6.5.

9.8.2.7 Unconfined intakes (Figure 9.8.2.7)

9.8.2.7.1 Scope

Unconfined intakes involve pumps installed on platforms or other structures where the intake lacks guide walls, walls of a sump, or other flow-guiding structures. Typical installations include intakes on rivers, canals or channels, lakes, and pumps located on platforms for seawater systems.

The unconfined intake design information provided is for pumps having flow rates no greater than 315 L/s (5000 gpm).

9.8.2.7.2 Cross-flow velocities and pump location

Pumps with unconfined intakes are often located where a unidirectional cross-flow occurs, or on platforms where tidal variations may cause highly complex current conditions around the pump inlet bell. The minimum recommended distance from an obstruction to the pump suction in the direction of any current that could cause wake effects is five times the maximum cross-sectional dimension of the obstruction. If an obstruction to the flow is downstream of the pump, the minimum recommended distance is 0.75 times the bell diameter of the pump.

Cross-flow velocities shall be less than 25% of the bell velocity, but the designer may have little control over this variable. Installations with higher cross-flow velocities require special flow correction devices, which are beyond this design standard (see Appendix A for reference information). For higher cross-flow velocities, supplemental lateral support of the pump may be required.

If debris or bottom sediments are not a problem, the inlet bell shall be located 0.3 to 0.5*D* above the bottom to minimize submerged vortices. For applications where suspension of bottom debris may be a problem, a 5*D* minimum clearance is suggested.

For installations on platforms along the seashore, suspension of sand during storms is unavoidable due to wave action. In some cases, a bed of armor stone around the intake has proved useful in minimizing suspension of

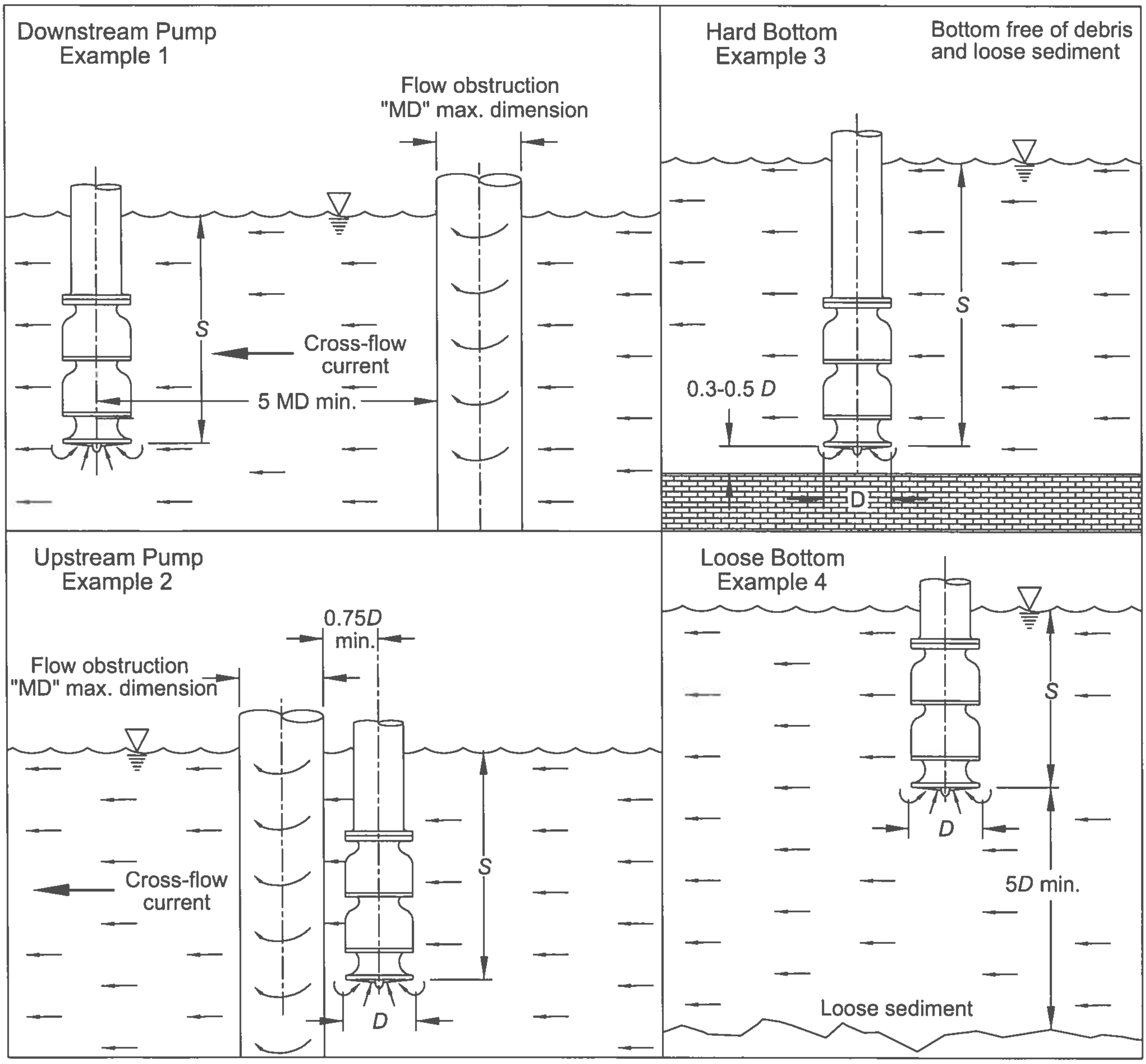


Figure 9.8.2.7 — Unconfined intakes

sediments. The design of such armor layers should be performed with the assistance of an engineer with experience in sediment transport and design of riprap protection, as the proper design of armor stone protection requires specialized techniques.

9.8.2.7.3 Debris and screens

Debris is of particular concern for unconfined intakes. Light debris loading may be accommodated by screens attached to the pump bell. Special design considerations are required to accommodate heavy debris loading.

Large floating debris and ice that could damage the pump is also of concern. A barrier may be required to protect the pump. These barriers should not introduce wake disturbances into the pump.

9.8.2.7.4 Submergence

$$\frac{S}{D} = 1.0 + 2.3F_D \qquad \text{(Eq. 9.8.2.7.4-1)}$$

Where:

F_D = Froude number = $\dfrac{V}{(gD)^{0.5}}$

D = outside diameter of suction bell

V = average suction bell velocity

For further discussion of submergence, see Section 9.8.6.

9.8.3 Intake structures for solids-bearing liquids

9.8.3.1 General

Wet wells for solids-bearing liquids require special considerations to allow for the removal of floating and settling solids. These considerations include wet-well geometry and provisions for cleaning of the structure to remove material that would otherwise be trapped and result in undesirable conditions.

Some dimensions given in this section may be impacted by actual pump geometry, or by specific product operational limitations. Where appropriate, these dimensions are indicated by the note "consult with manufacturer." Model studies shall be conducted for any installation with individual pump capacities exceeding 2520 L/s (40,000 gpm) or stations with capacities greater than 6310 L/s (100,000 gpm).

9.8.3.1.1 Scope

This section applies specifically to installations where the pumped liquid contains solids that may float or settle in the wet well. Fluids such as wastewater, industrial discharges, storm or canal drainage, combined wastewater, and some raw water supplies are included in this category.

9.8.3.1.2 Objectives

The objective of this part of the standard is to introduce special design features recommended for wet wells used in solids-bearing liquid applications. These features are intended to eliminate or minimize accumulations of solids, thereby reducing maintenance. Organic solids accumulations not removed may become septic, causing odors, increasing corrosion, and releasing hazardous gases.

9.8.3.1.3 Principles

The design of a solids-bearing wet well must both provide for proper approach flow to the pumps as described in Section 9.8.1, and prevent the accumulation of sediments and surface scum in the sump. The main principle is to minimize horizontal surfaces in the wet well anywhere but directly within the influence of the pump inlets, thereby directing all solids to a location where they may be removed by the pumping equipment. Vertical or steeply sloped sides shall be provided for the transition from upstream conduits or channels to pump inlets.

The following points shall be considered in addition to those found in Section 9.8.1:

- Flow of liquid from the sump entrance should be directed toward the pump inlets in such a way that the flow reaches the inlets with a minimum of swirl.
- Although excessive turbulence or large eddies should be avoided, some turbulence does help to prevent the formation and growth of vortices.
- Sediment, which could become septic, must not accumulate within the sump. Stagnant regions or regions of such low velocity where sedimentation might occur shall be avoided. A sloping floor and fillets (or benching) often helps to reduce sedimentation. For large variations in flow, part of the sump can be dedicated to low inflows with a lower floor level and a smaller pump.
- Surface scum, floating sludge, and debris can accumulate in any relatively calm region of the liquid surface; and this material must be pumped away. The liquid level should be intermittently lowered as much as possible to increase both velocity and turbulence near the sump bottom; however, air should not be drawn into the pump. The occasional increases in velocity will also assist in removing the accumulation of sediment on the floor.
- The sump should be as small and as simple as feasible; however, a minimum required sump volume may be specified for other reasons, such as to provide for a minimum retention time or to ensure that only a certain number of pump starts per hour occur.

9.8.3.1.4 Vertical transitions

Transitions between levels in wet wells for solids-bearing liquids shall be at steep angles (60 degrees minimum for concrete, 45 degrees minimum for smooth-surfaced materials such as plastic and coated concrete; all angles relative to horizontal) to prevent solids accumulations and promote movement of the material to a location within the influence of the currents entering the pump intakes. Horizontal surfaces should be eliminated where possible except near the pump inlet. See Figure 9.8.3.2.2.

9.8.3.1.5 Confined inlet

The horizontal surface immediately in front (for formed suction inlets) or below (for bell inlets) should be limited to a small, confined space directly in front of or below the inlet itself. To make cleaning more effective, the walls and floor forming the space must be confined so that currents can sweep floating and settled solids to the pump inlet. See Figure 9.8.3.4.4.

9.8.3.1.6 Cleaning procedures

Removal of solids from wet wells, designed in accordance with these principles, can be achieved by operating the pumps selectively to lower the level in the wet well until the pumps lose prime. Both settled and floating solids are removed by the pumping equipment and discharged to the force main (or discharge conduit). This cleaning procedure momentarily subjects the pumps to vibration, dry running, and other severe conditions. Consult the pump manufacturer before selecting the pumping equipment. The frequency of cleaning cycles depends on local conditions, and therefore should be determined by experience at the site.

Alternatively, liquid jets or mixers positioned to create horizontal and vertical currents can be used intermittently or continuously to maintain suspension and direct floating and settled solids toward the pump intakes. The solids are swept into the pump intake for removal. Caution should be exercised when using jets or mixers to avoid inducing continuous currents near pump inlets that could result in damage to the pumping equipment.

9.8.3.1.7 Wet-well volume

Wet wells for variable-speed pumping stations designed to match outflow with inflow need not be designed for storage, but rather only to accommodate the inlets and the geometry required for velocity limitations and cleaning.

Wet wells for constant-speed pumps should be constructed to minimize size for economy and to facilitate cleaning. One approach is to provide storage for pump regulation in the upstream conduit or channel, as well as in the wet well itself. Refer to Appendix B for guidance on sump volume for constant-speed pumps and Appendix C for storage in the upstream conduit.

CAUTION: While no storage volume is required for continuous operation, the designer should provide adequate volume to avoid inappropriately short time intervals, which could damage pump motors, between pump starts.

9.8.3.2 Trench-type wet wells for solids-bearing liquids

9.8.3.2.1 General

The purpose of this section is to establish criteria for design of trench-type wet wells for solids-bearing liquids such as stormwater, wastewater, and canal-type pumping stations.

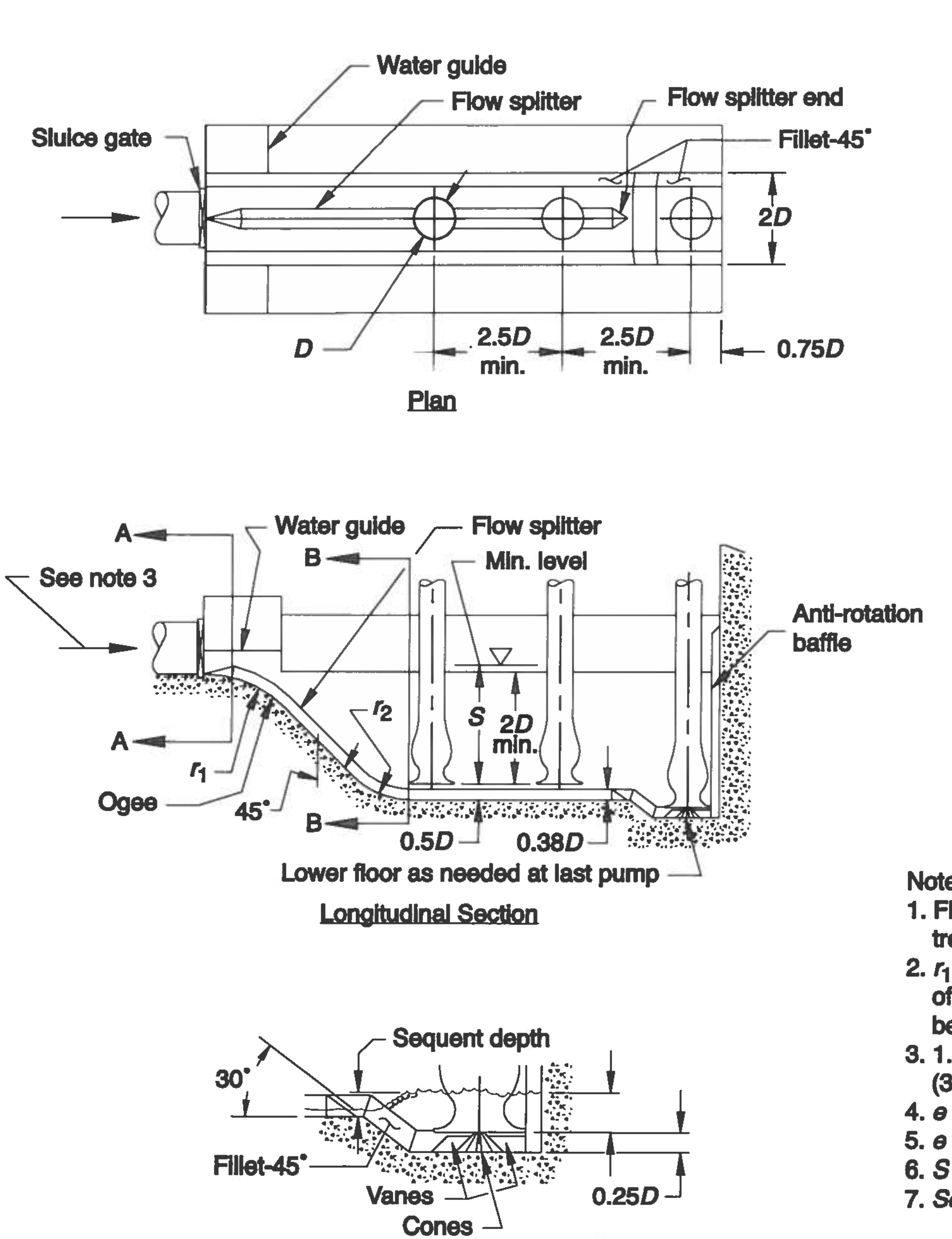
9.8.3.2.2 Objectives

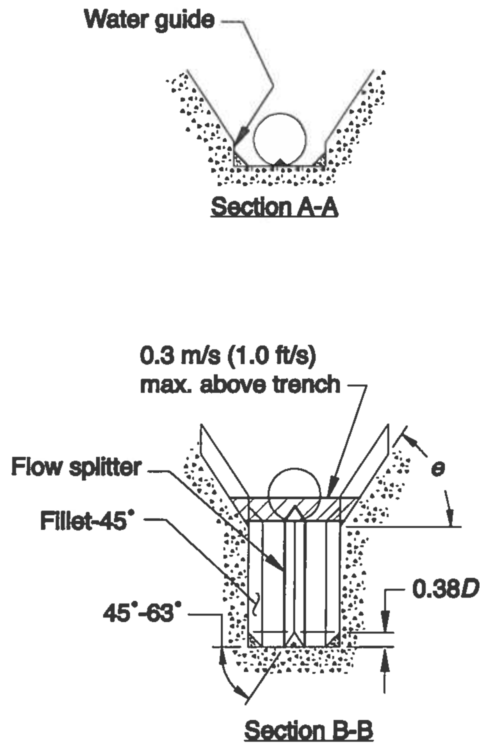
Trench-type wet wells are designed to provide for cleaning with the periodic operation of the pumping equipment using a special procedure. This standard provides guidance on the geometry necessary to induce scouring velocities during the cleaning procedure. Experience has shown that trench-type wet wells with an ogee transition between the entrance conduit and the trench floor provides optimum geometry for efficient cleaning operations.

Refer to Sections 9.8.3.2.3 to 9.8.3.2.3.5 and Figure 9.8.3.2.2 for recommendations for trench-type wet wells. Trench-type wet wells can be used with both constant-speed and variable-speed pumping equipment.

There is no difference between wet wells for variable as compared with constant-speed pumps, but there is a difference between inlet conduits for the two kinds of pumping stations. With variable-speed pumps, there is no need for storage if pump discharge equals well inflow. Consequently, the liquid level in the wet well can be made to match the liquid level in the upstream conduit.

When constant-speed pumps are used, the liquid level must fluctuate – rising when pumps are off and falling when they are running. There must be sufficient active storage to prevent excessive frequency of motor starts. As trench-type wet wells are inherently small and not easily adapted to contain large volumes of active storage, it is desirable to dedicate a portion of the upstream conduit to storage. The dedicated portion is called an *approach pipe*. It is usually 75 to 150 mm (3 to 6 in) larger than the conduit upstream of the dedicated portion, and it is laid at a compromise gradient of 2% (although other gradients could be used.) At low liquid level, the velocity in the approach pipe is supercritical, thus leaving a large part of the cross section empty for storage as the liquid level rises. The design of approach pipes is not a part of these standards, but the essentials of design are given in Appendix C.





Notes:
1. Flow splitter and fillets may be omitted in a trench less than 1.0 m (39 in) wide.
2. $r_1 \geq 2.33 \times v^2/2g$, where v = velocity at top of ramp (2D min.), $r_2 \geq 1.25D$, 45° tangent between r_1 and r_2.
3. 1.2 m/s (4 ft/s) max. wet-pit pumps, 1.0 m/s (3 ft/s) max. dry-pit pumps.
4. $e \geq 45°$ smooth surface (plastic lining).
5. $e \geq 60°$ concrete surface.
6. $S \geq (1 + 2.3F_D)D$.
7. *See* Appendix D for details and tutorials.

Figure 9.8.3.2.2 — Open trench-type wet well

9.8.3.2.3 Approach flow

The velocity in the approach channel or conduit, upstream from the wet well, shall be no greater than:

- 1.2 m/s (4.0 ft/s) with the axis of the channel or conduit coaxial with the axis of the wet well for vertical pumps or submersible pumps

- 0.9 m/s (3.0 ft/s) with the axis of the channel or conduit coaxial with the axis of the wet well for pumps with suction piping extending from the dry well into the wet well

The influent pipe upstream from the trench shall be straight and free of fittings or devices that will disrupt the flow uniformity entering the trench for a distance equal to at least eight times the influent pipe diameter.

9.8.3.2.3.1 Inlet transition

The ogee spillway transition at the inlet to the wet-well trench is designed to convert potential energy in the influent liquid to kinetic energy during the wet-well cleaning cycle. The curvature at the top of the spillway should follow the trajectory of a free, horizontal jet issuing from under the sluice gate and discharging approximately 75% of the flow rate of the last pump. The radius of the curvature, r, shall be at least 2.3 times the pressure head upstream of the sluice gate during cleaning. The radius of curvature at the bottom of the ogee needs to be large enough only for a smooth transition to horizontal flow; 0.5 to $1.0r$ is sufficient.

To produce smooth flow down the ogee ramp and avoid standing waves, the discharge under the sluice gate should be uniform in depth across the $2D$ width of the trench. Either (1) a short transition from a circular to a rectangular section, as shown in Figure 9.8.3.2.2 or (2) a short rectangular recess in front of the sluice gate is recommended.

9.8.3.2.3.2 Inlet floor clearance

All bell-type pump inlets, except that farthest from the wet-well inlet, shall be located $0.5D$ above the floor of the wet-well trench. The inlet for the last pump (farthest from the wet-well inlet) shall be located $0.25D$ above the floor of the trench. See Figure 9.8.3.2.2.

For pumps that may be sensitive to loss of prime (due to entrainment of air from surface vortices), the last pump inlet can be lowered by $0.25D$ provided the floor near the intake is lowered by the same amount. All other dimensions and velocities for this arrangement shall comply with those given in Figure 9.8.3.2.2.

For submersible wastewater pumps, an inlet extension and nozzle, sized for a peak entrance velocity not to exceed the velocity of 1.7 m/s (5.5 ft/s) and fitted to the pump inlet, is necessary to meet the dimensional requirements for development of the trench.

9.8.3.2.3.3 Inlet splitters and cones

Floor-mounted flow splitters aligned with the axis of the trench are recommended. They must be centered under the suction bells for all but the pump inlet farthest from the wet-well entrance. A floor cone should be installed under the pump inlet farthest from the wet-well inlet conduit or pipe as shown in Figure 9.8.3.2.2.

9.8.3.2.3.4 Anti-rotation baffle and vanes

An anti-rotation baffle positioned on the wall at the last pump inlet, shown in Figure 9.8.3.2.2, is needed to ensure satisfactory performance during the cleaning cycle. The anti-rotation baffle should protrude towards the pump as far as practicable. Vanes in line with this baffle are needed on either side of the floor cone, with a height as high as practicable yet compatible with the $0.25D$ bell clearance at that pump inlet.

9.8.3.2.3.5 Cleaning procedure

Trench-type wet wells for solids-bearing liquids can be quickly cleaned by choosing a time when the inflow is about half of the capacity of the last pump. If that pump, operating at full speed, takes more than about a minute to lower the liquid level to the middle of the trench, two pumps can be activated. The liquid flowing down the ramp reaches supercritical velocity and forms a hydraulic jump that, taking all solids with it, moves to the last pump. The Froude number before the jump at the last pump should be no less than 3.5. Informative material regarding trench-type, wet-well calculations is located in Appendix L. If the inflow is insufficient for cleaning, enough liquid to complete the cleaning cycle can be stored in the upstream conduits by stopping all pumps for a short time. If the inflow is too high, two pumps can be operated to produce enough turbulence to clean the trench. The hydraulic jump should move from the toe of the ramp to the last pump in no more than 30 seconds, because operation at low intake submergence is severe service for the pump. As the hydraulic jump passes under each pump intake, the pump loses prime and should be stopped.

Note: Pumps must be reprimed prior to the next start.

This cleaning procedure, a push-button operation that theoretically can be completed in less than three or four minutes, rids the wet well of all sludge, grit, and scum, but grease accumulations on walls between normal high and low liquid levels must be manually hosed off from time to time. An epoxy coating or PVC lining is substantially better than concrete for ease and speed of the washing process. Varying the high liquid level a few inches changes the rim of grease formed at high liquid level into a band and somewhat prolongs the intervals between hosings. A liquid flow rate of 1.6 L/s (25 gal/min) at a nozzle Pitot pressure of 620 kPa (90 lb/in^2) is adequate. The wet well should be designed for convenience and ease in washing the walls.

9.8.3.3 Circular plan wet pit for solids-bearing liquids

9.8.3.3.1 Wet-pit design

The design of the wet pit should adhere to the general recommendations given in Section 9.8.2.3. As stated in that section, circular pump sumps for flows exceeding 315 L/s (5000 gpm) per pump require a physical model study. Additionally, the bottom of the wet pit shall have sloped surfaces around the inlet bells or pumps, as shown in Figures 9.8.3.3.1a, b, and c. The designs shown in this section are based on single pump operation, i.e., one duty pump and one installed spare.

9.8.3.3.2 Accessories

The use of pump and sump accessories that cause collection or entrapment of solids should be limited to a practical minimum.

9.8.3.3.3 Cleaning procedure and low liquid level

The frequency of cleaning cycles depends on local conditions, and therefore should be determined by experience at the site. Removal of settled solids is effected each time a pump is activated, but to aid in the removal of floating solids, the wet well may need to be pumped down below the level of minimum submergence, to a level equal to a submergence of 0.5 to 1.0*D*. Such a submergence level is lower than that recommended in Section 9.8.6. In this case, the liquid surface area is at a minimum and the pump intake submergence is low enough to create a strong surface vortex (numbers 4 through 6 in Figure 9.8.4.5a-i). This level is called the *low liquid level*. Pumping under these severe conditions will cause noise, vibration, and high loads on the impeller and hence should be limited to a period as recommended by the pump manufacturer. The pumps should be stopped as soon as they lose prime, or as soon as the sump is free of floating debris.

9.8.3.3.4 Floor clearance *C*

The recommended floor clearance *C* is between 0.3 and 0.5*D*. In certain cases this clearance may need to be larger, depending on the size of expected solids in the liquid relative to the calculated value of *C*.

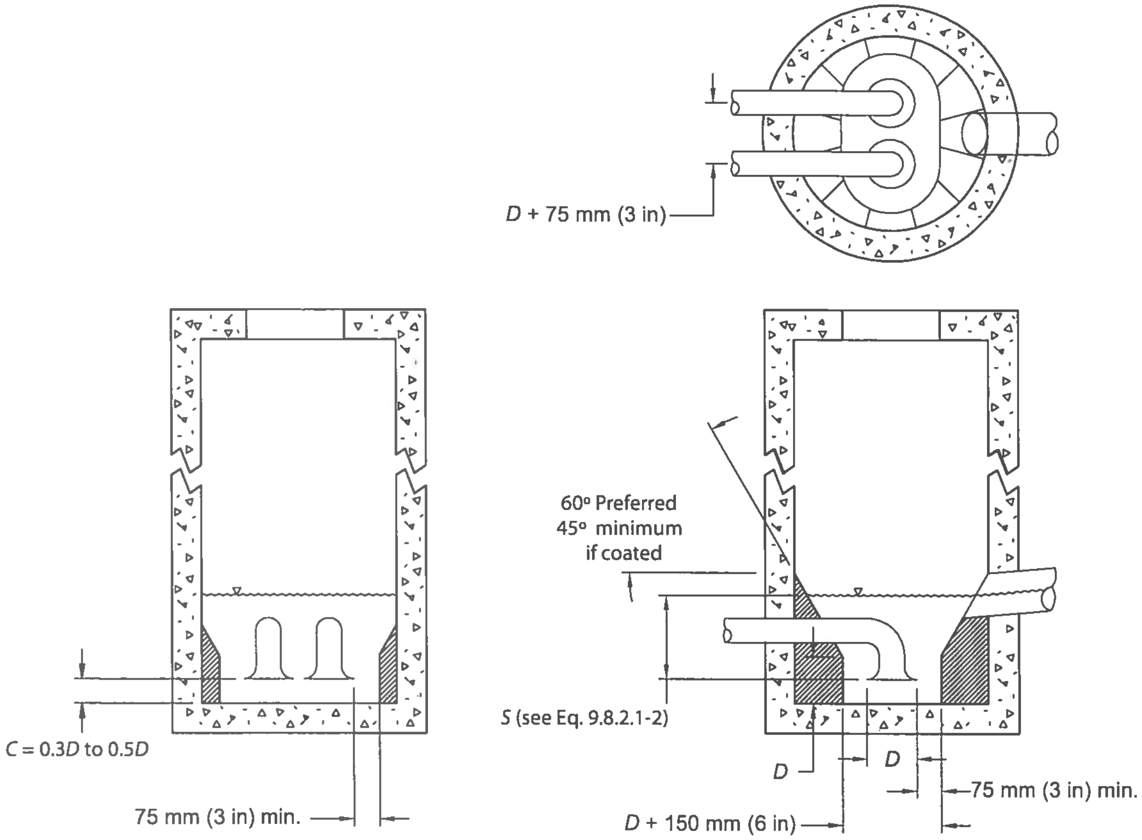


Figure 9.8.3.3.1a — Circular wet pit with sloping walls and minimized horizontal floor area (dry-pit pumps)

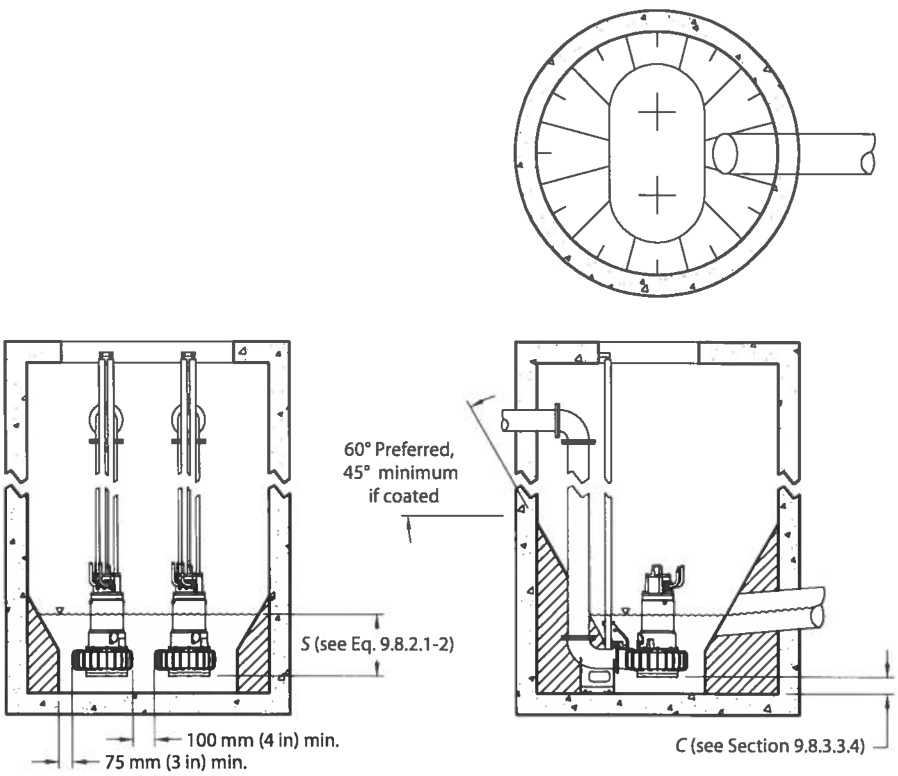


Figure 9.8.3.3.1b — Circular wet pit with sloping walls and minimized horizontal floor area (submersible pumps shown for illustration)

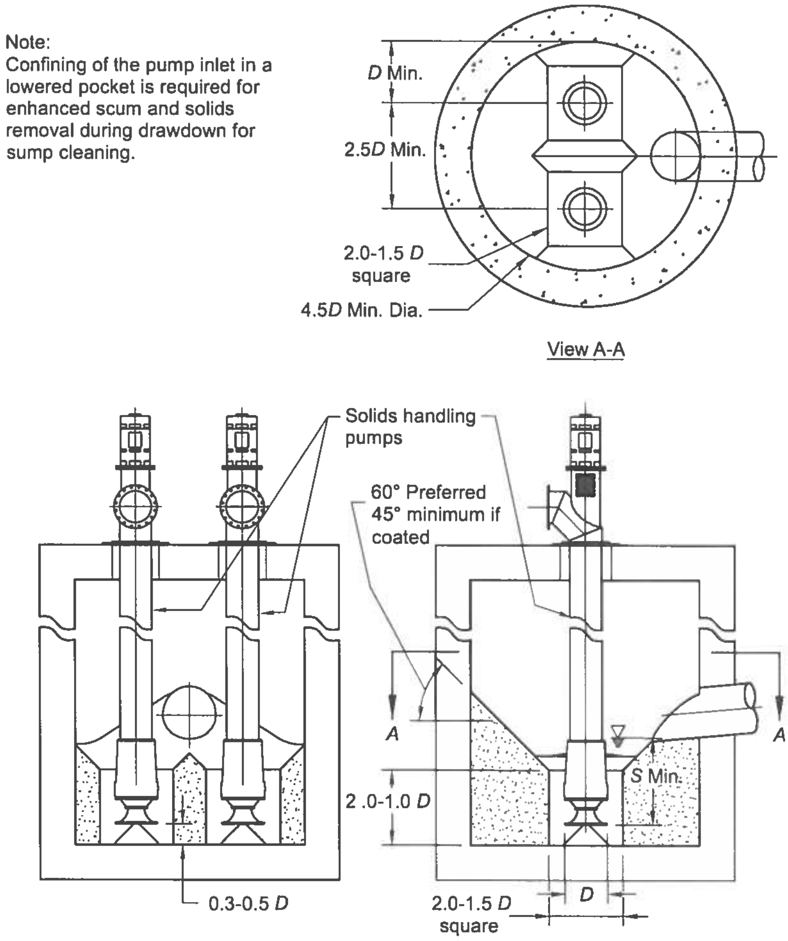


Figure 9.8.3.3.1c — Circular wet pit with sloping walls and minimized horizontal floor area (wet-pit pumps shown for illustration)

9.8.3.4 Rectangular wet wells for solids-bearing liquids

9.8.3.4.1 General

The geometry of rectangular wet wells is not particularly suited for use with solids-bearing liquids, but with special provisions for frequent cleaning, such wet wells may be acceptable.

9.8.3.4.2 Objectives

The objective of this section is to describe several means for minimizing or eliminating accumulations of solids before they interfere with the operation of the pumps or before they become septic and generate excessive odors that must be treated.

9.8.3.4.3 Control of sediments

Several means for controlling the accumulation of sediments are possible, such as:

- Designing the wet well to provide currents swift enough (e.g., 1.0 m/s [3.0 ft/s] or more) to carry settleable solids to the pump intakes.

- Violent mixing to suspend sediments while the mixture is being removed by the main pumps. These methods include:
  - Use of submerged mixers.
  - Connecting the pump discharge or force main to a valve and into the wet well. About half of the pump discharge is allowed to recirculate back into the wet well.
- Dewatering the wet well and sweeping solids to the pumps with a high-pressure hose.
- Vacuuming both floating and settled solids out of the wet well, usually by an external pump and hose.
- Dewatering one side of the wet well (if possible) and removing the solids.

9.8.3.4.4 Confined wet-well design

In this arrangement each suction inlet bell is located in a confined pocket to isolate the pump from any flow disturbances that might be generated by adjacent pumps, to restrict the area in which solids can settle, and to maintain higher velocities at the suction inlet to minimize the amount of solids settling out of the flow.

See Figure 9.8.3.4.4 for the arrangement of a confined wet well.

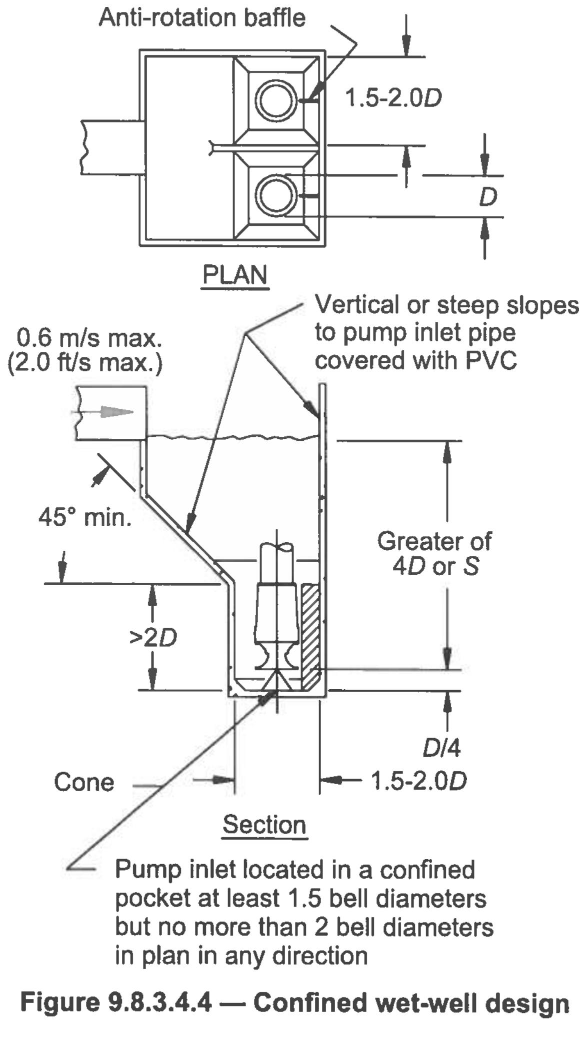


Figure 9.8.3.4.4 — Confined wet-well design

9.8.3.4.4.1 Suction inlet clearance

All suction inlets shall be located *D*/4 above the floor of the wet well unless otherwise recommended by the manufacturer. The sidewalls of the individual cell should be 1.5 to 2.0*D* in dimension. The depth of the individual cell must be a minimum of 2.0*D* square. A cone shall be installed under each suction inlet.

9.8.3.4.4.2 Anti-rotation baffle

Anti-rotation baffles are required for individual flows in excess of 189 L/s (3000 gpm).

9.8.3.4.4.3 Cleaning procedure

Removal of settled solids from wet wells, designed in accordance with Figure 9.8.3.4.4, can be achieved by operating the pumps one at a time at full speed for a duration of about two minutes. Typically, only one pump should be operated at a time to avoid excessive drawdown of the liquid level in the sump.

The majority of floating solids are removed from the sump by operating the pumps one at a time at full speed while restricting the flow into the wet well to 80 to 60% of the flow rate of the pump at full speed. Adjusting the sluice gate is the normal method of flow restriction. As the liquid level in the wet well falls, swift currents will suspend most of the floating debris, causing them to be pumped from the trench. The pump will eventually lose prime and must be stopped immediately.

Both settled and floating solids are removed by the pumping equipment and discharged to the force main (or discharge conduit). This cleaning procedure momentarily subjects the pumps to vibration, dry running, and other severe conditions. The frequency of cleaning cycles depends on local conditions, and therefore should be determined by experience at the site. Normally, the cleaning operation will take less than five minutes to perform and the duration between cleaning cycles would typically be one to two weeks.

9.8.4 Physical model studies of intake structures and pump suction piping

9.8.4.1 Need for a physical model study

A properly conducted physical model study is a reliable method to identify unacceptable flow patterns at the pump suction for given sump or suction piping designs and to derive acceptable intake sump or piping designs. Considering the cost for a physical model study, an evaluation is needed to determine if one is required. A physical hydraulic model study shall be conducted for pump intakes with one or more of the following features:

- Sump or piping geometry (such as bay width, bell clearances, sidewall angles, bottom slopes, distance from obstructions, the bell diameter, or piping changes, etc.) that deviates from this standard.
- Nonuniform or nonsymmetric approach flow to the pump sump exists (e.g., intake from a significant cross-flow, use of dual flow or drum screens, or a short-radius pipe bend near the pump suction, etc.).
- The pumps have flows greater than 2520 L/s (40,000 gpm) per pump or the total station flow with all pumps running would be greater than 6310 L/s (100,000 gpm).
- Circular pump sumps (clear or solids-bearing liquids) with flows exceeding 315 L/s (5000 gpm) per pump require a physical model study (see Sections 9.8.2.3 and 9.8.3.3). Circular pump sumps (clear liquids) per Figures 9.8.2.3.1c and 9.8.2.3.1f with station flows exceeding 315 L/s (5000 gpm) require a physical model study.
- The pumps of an open bottom barrel or riser arrangement with flows greater than 315 L/s (5000 gpm) per pump (see Section 9.8.2.6).
- The pump of a closed bottom can intake has flows greater than 630 L/s (10,000 gpm) (see Section 9.8.2.6).

- Proper pump operation is critical and pump repair, remediation of a poor design, and the impacts of inadequate performance or pump failure all together would cost more than 10 times the cost of a physical model study.

When evaluating the impacts of inadequate performance or pump failures, the probability of failure may be considered, such as by comparing the proposed intake design to other intakes of essentially identical design and approach flow that operate successfully. The physical model study shall be conducted by a hydraulic laboratory using personnel that have experience in modeling pump intakes.

9.8.4.2 Physical model study objectives

Adverse hydraulic conditions that can affect pump performance include free and subsurface vortices, swirl approaching the pump impeller, flow separation at the pump bell, and a nonuniform axial velocity distribution at the suction.

Free surface vortices are detrimental when their core is strong enough to cause a (localized) low pressure at the impeller and because a vortex core implies a rotating rather than a radial flow pattern. Subsurface vortices also have low core pressures and are closer to the impeller. Strong vortex cores may induce fluctuating forces on the impeller and cavitation. Subsurface vortices with a dry-pit suction inlet are not of concern if the vortex core and the associated swirling flow dissipate well before reaching the pump suction flange.

Preswirl in the flow entering the pump exists if a tangential component of velocity is present in addition to the axial component. Swirl alters the inlet velocity vector at the impeller vanes, resulting in undesired changes in pump performance characteristics, including potential vibration.

A reasonably uniform axial velocity distribution in the suction flow (approaching the impeller) is assumed in the pump design, and nonuniformity of the axial velocity may cause uneven loading of the impeller and bearings.

A properly conducted physical model study can be used to derive remedial measures, if necessary, to alleviate these undesirable flow conditions due to the approach upstream from the pump impeller. The typical hydraulic model study is not intended to investigate flow patterns induced by the pump itself or the flow patterns within the pump. The objective of a model study is to ensure that the final sump or piping design generates favorable flow conditions at the inlet to the pump.

9.8.4.3 Physical model similitude and scale selection

Physical models involving a free surface are operated using Froude similarity because the flow process is controlled by gravity and inertial forces. The Froude number, representing the ratio of inertial to gravitational forces, can be defined for pump intakes as:

$$F = \frac{u}{(gL)^{0.5}} \qquad \text{(Eq. 9.8.4.3-1)}$$

Where:

u = average axial velocity (such as in the suction bell)

g = gravitational acceleration

L = a characteristic length (usually bell diameter or submergence)

The choice of parameter used for velocity and length is not critical, but the same parameter must be used in the model and prototype when determining the Froude number.

For similarity of flow patterns, the Froude number shall be equal in model and prototype:

$$F_r = \frac{F_m}{F_p} = 1 \qquad \text{(Eq. 9.8.4.3-2)}$$

where *m*, *p*, and *r* denote model, prototype, and the ratio between model and prototype parameters, respectively.

In physically modeling a pump intake to study the potential formation of vortices, it is important to select a reasonably large geometric scale to minimize viscous and surface tension scale effects, and to reproduce the flow pattern in the vicinity of the intake. Also, the model shall be large enough to allow visual observations of flow patterns, accurate measurements of swirl and velocity distribution, and sufficient dimensional control. Realizing that larger models, though more accurate and reliable, are more expensive, a balancing of these factors is used in selecting a model scale. However, the scale selection based on vortex similitude considerations, discussed below, is a requirement to avoid scale effects and unreliable test results.

Fluid motions involving vortex formation have been studied by several investigators (Anwar, H.O. et al., 1978; Hecker, G.E., 1981; Padmanabhan, M. and Hecker, G.E., 1984; Knauss, J., 1987). It can be shown by the principles of dimensional analysis that such flow conditions at an intake are governed by the following dimensionless parameters:

$$\frac{uD}{\Gamma}, \frac{u}{(gD)^{0.5}}, \frac{D}{S}, \frac{uD}{\nu}, \text{ and } \frac{u^2 D}{\left(\frac{\sigma}{\rho}\right)}$$

Where:

u = average axial velocity (e.g., at the bell entrance)

Γ = circulation of the flow

D = diameter (of the bell entrance)

S = submergence (at the bell entrance)

ν = kinematic viscosity of the liquid

g = acceleration due to gravity

σ = surface tension of liquid/air interface

ρ = liquid density

The influence of viscous effects is defined by the parameter $\frac{uD}{\nu} = R$, the Reynolds number, and surface tension effects are indicated by $\frac{u^2 D}{\left(\frac{\sigma}{\rho}\right)} = We$, the Weber number. Based on the available literature, the influence of viscous forces and surface tension on vortexing may be negligible if the values of R and W_e in the model fall above 3×10^4 and 120, respectively (Daggett, L., and Keulegan, G.H., 1974; Jain, A.K. et al., 1978).

With negligible viscous and surface tension effects, dynamic similarity is obtained by equating the parameters $\frac{uD}{\Gamma}$, $\frac{u}{(gD)^{0.5}}$, and $\frac{D}{S}$ in the model and prototype. An undistorted geometrically scaled Froude model satisfies this condition, provided the approach flow pattern in the vicinity of the sump, which governs the circulation, Γ, is properly simulated.

Based on the above similitude considerations and including a safety factor of 2 to ensure minimum scale effects, the model geometric scale shall be chosen so that the model bell entrance Reynolds number and Weber number are above 6×10^4 and 240, respectively, for the test conditions based on Froude similitude. No specific geometric scale ratio is recommended, but the resulting dimensionless numbers must meet these minimum values. For practicality in observing flow patterns and obtaining accurate measurements, the model scale shall yield a bay width of at least 300 mm (12 in), a minimum liquid depth of at least 150 mm (6 in), and a pump throat or suction diameter of at least 80 mm (3 in) in the model.

In a model of geometric scale L_r, with the model operated based on Froude scaling, the velocity, flow, and time scales are, respectively:

$$V_r = \frac{V_m}{V_p} = L_r^{0.5} \qquad \text{(Eq. 9.8.4.3-3)}$$

$$Q_r = \frac{Q_m}{Q_p} = L_r^2 V_r = L_r^{2.5} \qquad \text{(Eq. 9.8.4.3-4)}$$

$$T_r = \frac{T_m}{T_p} = \frac{L_r}{V_r} = L_r^{0.5} \qquad \text{(Eq. 9.8.4.3-5)}$$

Even though no scale effect of any significance is probable in models with geometric scales selected as described above, as a conservative procedure conforming to common practice, a few tests for the final design of a free surface intake shall be conducted at 1.5 times the Froude scaled flows, keeping the submergence at the geometrically scaled values. By this procedure, the circulation contributing to vortices would presumably be increased, resulting in a conservative prediction of (stronger) vortices. Tests at prototype velocities are not recommended, as this will distort approach flow patterns and unduly exaggerate flow disturbances (e.g., vortices) in the model.

Models of closed-conduit piping systems leading to a pump suction are not operated based on Froude similitude, but need to have a sufficiently high pipe Reynolds number, $R = \frac{uD}{\nu}$, such that flow patterns are correctly scaled. Based on available data on the variation of loss coefficients and swirl with Reynolds number, a minimum value of 1×10^5 is recommended for the Reynolds number at the pump suction.

9.8.4.4 Physical model study scope

Selection of the model boundary is extremely important for proper simulation of flow patterns at the pump. As the approach flow nonuniformities contribute significantly to the circulation causing preswirl and vortices, a sufficient area of the approach geometry or length of piping has to be modeled, including any channel or piping transitions, bends, bottom slope changes, control gates, expansions, and any significant cross-flow past the intake.

All pertinent sump structures or piping features affecting the flow, such as screens and blockage due to their structural features, trash racks, dividing walls, columns, curtain walls, flow distributors, and piping transitions must be modeled. Special care should be taken in modeling screens; the screen head loss coefficient in the model shall be the same as in the prototype. The head loss coefficient is a function of the screen Reynolds number, the percent open area, and the screen (wire) geometry. Scaling of the prototype screen wire diameter and mesh size to the selected model geometric scale may be impractical and improper due to the resulting low model Reynolds number. In some cases, a model could use the same screen as the prototype to allow equal loss coefficients. Scaling of trash racks bars may also be impractical and lead to insufficient model bar Reynolds number. Fewer bars producing the same total blockage and the same flow guidance effect (bar to space aspect ratio) may be more appropriate.

The inside geometry of the bell (and hub, if modeled) up to the bell throat (section of maximum velocity) shall be scaled. Any hub located between the bell entrance and the throat shall be modeled if the hub occupies 10% or more of the throat area. In such cases, the hub shall extend downstream beyond the throat to prevent flow separation in the annular velocity measuring plane. Supports for the hub shall be round rods placed so as to not dissipate any preswirl generated by the approach flow or influence the velocity data. Similarly, any vanes in the bell shall not be modeled. The bell should be modeled of clear plastic or smooth fiberglass, the former being preferred for flow visualization. The outside shape of the bell may be approximated except in the case of multistage pumps, in which case the external shape may affect flow patterns approaching the inlet bell. The impeller is not included in physical models, as the objective is to evaluate the effect of the intake design on flow patterns approaching the impeller. A straight pipe equal to the throat diameter or pump suction diameter shall extend at least five diameters downstream from the throat or pump suction.

For free surface intakes, the model shall provide up to 1.5 times the Froude scaled maximum flow per pump to evaluate potential scale effects on free surface vortices, as discussed above, and be deep enough to cover the range of scaled submergence.

9.8.4.5 Instrumentation and measuring techniques

Unless agreed on circumstances indicate otherwise, the following measurements shall be made. The extent of the measurements is summarized in Section 9.8.4.6, Test plan, below.

Flow: The outflow from each simulated pump shall be measured with flowmeters. If an orifice or venturi meter conforming to ASME standards is used, the meter need not be calibrated. The accuracy of the flow measurement shall be within ±2% of the actual flow rate.

Liquid level: Liquid surface elevations shall be measured using any type of liquid level indicator accurate to at least 3 mm (0.01 ft) in the model.

Free surface vortices: To evaluate the strength of vortices at pump intakes systematically, the vortex strength scale varying from a surface swirl or dimple to an air core vortex, shown in Figure 9.8.4.5a, shall be used. Vortex types are identified in the model by visual observations with the help of dye and artificial debris, and identification of a coherent dye core to the pump bell or pump suction flange is important. Vortices are usually unsteady in strength and intermittent in occurrence. Hence, an indication of the persistence of varying vortex strengths (types) shall be obtained through observations made at short intervals in the model (e.g., every 15 seconds) for at least 10 minutes, so that a vortex type versus frequency evaluation can be made and accurate average and maximum vortex types may be determined. Such detailed vortex observations are needed only if coherent dye core (or stronger) vortices exist for any test. Photographic or video documentation of vortices is recommended.

Subsurface vortices: Subsurface vortices usually terminate at the sump floor and walls, and may be visible only when dye is injected near the vortex core. The classification of subsurface vortices, given in Figure 9.8.4.5a-ii, shall be used. The possible existence of subsurface vortices must be explored by dye injection at all locations on the wall and floor around the suction bell where a vortex may form, and documentation of persistence shall be made, as for free surface vortices.

Preswirl: Visual observations of the orientation of eight or more equally spaced yarns mounted to form a circle equal to the (outer) bell diameter and originating about one half the bell floor clearance are useful (but not required) to evaluate qualitatively any preswirl at the bell entrance. The yarns shall be one half the bell-to-floor clearance in length.

Swirl in the suction pipe: The intensity of flow rotation shall be measured using a swirl meter, see Figure 9.8.4.5b, located about four suction pipe diameters downstream from the bell or pump suction. The swirl meter shall consist

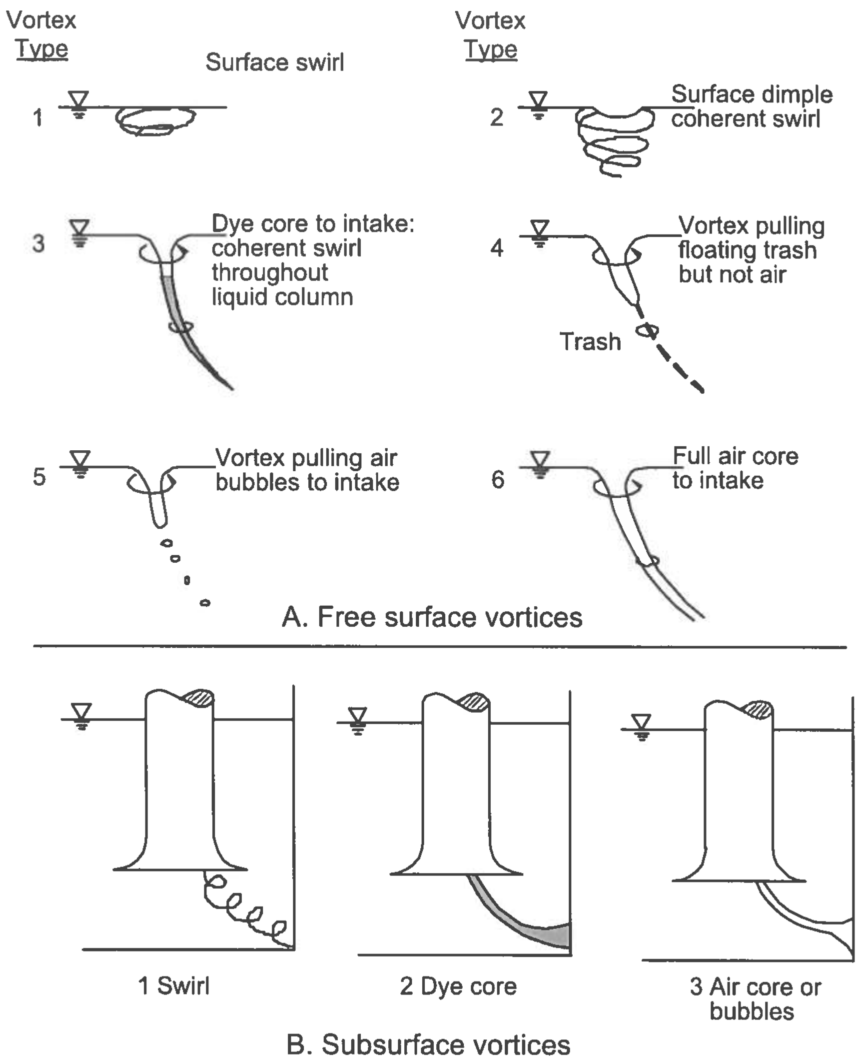


Figure 9.8.4.5a — Classification of free surface and subsurface vortices

of a straight-vaned propeller with four vanes mounted on a shaft with low-friction bearings. The tip-to-tip vane diameter is 75% of the pipe diameter and the vane length (in the flow direction) is equal to 0.6 pipe diameters. The revolutions per unit time of the swirl meter are used to calculate a swirl angle, θ, which is indicative of the intensity of flow rotation.

$$\theta = \tan^{-1}\left(\frac{\pi d n}{u}\right) \qquad \text{(Eq. 9.8.4.5-1)}$$

Where:

u = average axial velocity at the swirl meter

d = diameter of the pipe at the swirl meter

n = revolutions/second of the swirl meter

Flow swirl is usually unsteady, both in direction of rotation and speed of rotation. Therefore, swirl meter readings shall be obtained continuously; for example, readings during consecutive intervals of 10 to 30 seconds, covering a period of at least 10 minutes in the model. Swirl meter rotation direction shall also be noted for each short duration. The maximum short duration swirl angle and an average swirl angle shall be calculated from the swirl meter rotations (see Section 9.8.4.7 Acceptance criteria below). When averaging the swirl meter reading over a timed interval, absolute values should be used, irrespective of rotation direction. Swirl at a dry-pit suction inlet is not of concern if the swirl dissipates before reaching the pump suction flange.

Velocity profiles: Cross-sectional velocity profiles of the approach flow may be obtained using a propeller meter or other suitable device at a sufficient number of measuring points to define any practical skewness in the approach flow. The cross-section location shall be selected to be representative of the approaching flow prior to being influenced by the pump, such as at a distance of two intake widths upstream from the pump centerline. Such measurements are in themselves not critical or required, but allow a better understanding of how the approach flow may be contributing to other flow irregularities and what type of remedial devices may be effective.

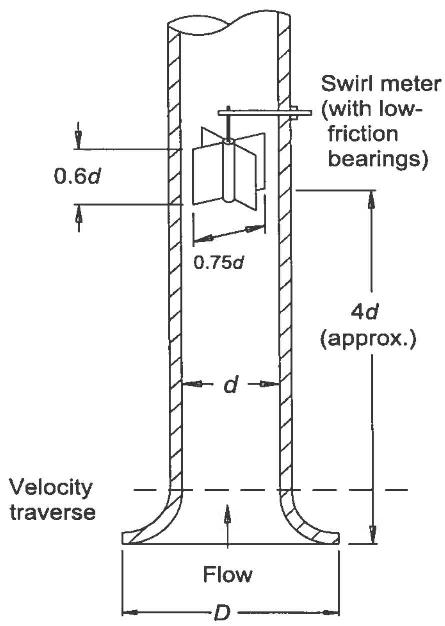


Figure 9.8.4.5b — Typical swirl meter

Velocity traverses along at least two perpendicular axes at the throat of the model suction bell or the plane of the pump suction in a piping system shall be obtained for the final design. A Pitot-static tube or other suitable instrument capable of determining the axial velocity component with a repeatability of ±2% or better shall be used. To allow velocity fluctuations to be properly measured and recorded versus time, care should be taken that no unnecessary physical or electronic damping is introduced. The angularity of the actual velocity vector relative to the axis of the pump or suction piping shall be observed at three or more locations with dye or strings to ensure that there are no large deviations from axial flow.

9.8.4.6 Test plan

Operating conditions to be tested shall include the minimum, intermediate, and maximum liquid levels and flows. If there are multiple pumps, all possible combinations of operating conditions should be included. Even though vortices are probably most severe at maximum flows and minimum submergence, there are instances where stronger vortices may occur at higher liquid levels and lower flows, perhaps due to less turbulence.

Vortex observations and swirl measurements shall be made for all tests. Axial velocity measurements at the bell throat or suction inlet for each pump in the model are recommended at least for the one test indicating the maximum swirl angle for the final design. Still-photographic documentation of typical tests showing vortexing or other flow problems shall be made.

The initial design shall be tested first to identify any hydraulic problems. If any objectionable flow problems are indicated, modifications to the intake or piping shall be made to obtain satisfactory hydraulic performance. Modifications may be derived using one or two selected test conditions indicating the most objectionable performance.

Practical aspects of installing the modifications should be considered. The performance of the final modified design shall be documented for all operating conditions. If any of the tests show unfavorable flow conditions, further revisions to the remedial devices shall be made. For intakes with a free surface, most tests shall be at Froude scaled flows; however, a few selected tests for the final design shall be repeated at 1.5 times the Froude scaled flows to compensate for any possible scale effects on free surface vortices. No velocity measurements shall be conducted at higher than Froude-scaled flows. It is recommended that representative tests of the final design be witnessed by the user, the pump manufacturer, and the station designer.

9.8.4.7 Acceptance criteria

The acceptance criteria for the model test of the final design shall be the following:

- Free surface and subsurface vortices entering the pump must be less severe than vortices with coherent (dye) cores (free surface vortices of Type 3 and subsurface vortices of Type 2 in Figure 9.8.4.5a). Dye core vortices may be acceptable only if they occur for less than 10% of the time or only for infrequent pump operating conditions.

- Swirl angles, both the short-term (10- to 30-second model) maximum and the long-term (10-minute model) average indicated by the swirl meter rotation, must be less than 5 degrees. Maximum short-term (10- to 30-second model) swirl angles up to 7 degrees may be acceptable, only if they occur less than 10% of the time or for infrequent pump operating conditions. The swirl meter rotation should be reasonably steady, with no abrupt changes in direction when rotating near the maximum allowable rate (angle).

- Time-averaged velocities at points in the throat of the bell or at the pump suction in a piping system shall be within 10% of the cross-sectional area average velocity. Time-varying fluctuations at a point shall produce a standard deviation from the time-averaged signal of less than 10%.

- For the special case of pumps with double suction impellers, the distribution of flow at the pump suction flange shall provide equal flows to each side of the pump within 3% of the total pump flow.

9.8.4.8 Report preparation

The final report of the model study shall include intake or piping design, model description, scaling and similitude criteria, instrumentation, test procedure, results (data tabulated and plotted), recommended modifications, and conclusions. The report shall contain photographs of the model showing the initial and final designs, drawings of any recommended modifications, and photographs of relevant flow conditions identified with dye or other tracers. A brief video tape of typical flow problems observed during the tests is recommended.

9.8.5 Inlet bell design diameter (*D*)

9.8.5.1 General

The purpose of this section is to provide criteria for the selection of a pump or suction pipe inlet bell design diameter, whether or not the actual pump ultimately to be used has been selected. The primary use of the inlet bell design diameter is for designing the sump. The actual pump bell diameter shall fall within the range dictated by the allowed range of inlet bell velocities.

9.8.5.2 Objective

Designing a sump to achieve favorable inflow to the pump or suction pipe bell requires control of various sump dimensions relative to a pump suction bell or inlet pipe bell diameter. For example, the clearance from the bell to the sump floor and sidewalls and the distance to various upstream intake features is controlled in these standards by expressing such distances in multiples of the pump suction bell or inlet pipe bell diameter. Such standardization of conditions leading to, and around, the inlet bell reduces the probability that strong submerged vortices or excessive preswirl will occur. Also, the required minimum submergence to prevent strong free surface vortices is related to the inlet bell diameter (see Section 9.8.6).

However, only the use of bell sizes within the guidelines provided in this section will produce sump dimensions that comply with these standards. Use of bell diameters outside the range recommended herein will also comply with these standards if a physical model study is conducted in accordance with Section 9.8.4 to confirm acceptable inflow conditions as required by Section 9.8.4.7.

It is recommended that the inlet bell diameter be chosen based on achieving the bell inlet velocity that experience indicates provides acceptable inflow conditions to the pump. The bell inlet velocity is defined as the flow through the bell (i.e., the pump flow) divided by the area of the bell, using the outside diameter of the bell. Information on acceptable average bell inlet diameters and velocities is provided in Figures 9.8.5.2a and b, based on a survey of inlet bell diameters used by pump vendors and industry experience. The solid line represents the average pump bell diameter from the survey, corresponding to a bell inlet velocity of 1.7 m/s (5.5 ft/s).

Industry experience indicates that the recommended inlet bell velocity V may vary as follows:

a) For flows less than 315 L/s (5000 gpm), the inlet bell velocity shall be 0.6 to 2.7 m/s (2.0 to 9.0 ft/s).

b) For flows equal to or greater than 315 L/s (5000 gpm), but less than 1260 L/s (20,000 gpm), the velocity shall be 0.9 to 2.4 m/s (3.0 to 8.0 ft/s).

c) For flows equal to or greater than 1260 L/s (20,000 gpm), the velocity shall be 1.2 to 2.1 m/s (4.0 to 7.0 ft/s).

These permissible ranges in inlet bell velocity are given in Tables 9.8.5.2a and b and are shown on Figures 9.8.5.2a and b (by the dashed lines) in terms of the recommended bell diameter range for a given flow per pump or inlet. These permissible ranges correspond to about one standard deviation of the range of inlet bell sizes that may be provided by pump vendors for a given flow. Although the survey indicated that pumps with bells outside this range may be proposed, experience indicates that inlet bell velocities higher than the recommended range may cause hydraulic problems and shall be verified with a physical model study. Use of lower velocities would produce unnecessarily large pump bells and, therefore, sumps.

For sump design prior to pump selection, the recommended inlet bell diameter shown by the solid line on Figures 9.8.5.2a and b shall be used. This recommended bell diameter is based on an inlet velocity of 1.7 m/s (5.5 ft/s).

Table 9.8.5.2a — Acceptable velocity ranges for inlet bell diameter *D* (metric units)

Pump Flow Range Q, L/s	Recommended Inlet Bell Design Velocity, m/s	Acceptable Velocity Range, m/s
< 315	$V = 1.7$	$0.6 \le V \le 2.7$
≥ 315 < 1260	$V = 1.7$	$0.9 \le V \le 2.4$
≥ 1260	$V = 1.7$	$1.2 \le V \le 2.1$

Note: See Figure 9.8.5.2a for corresponding inlet diameters calculated according to

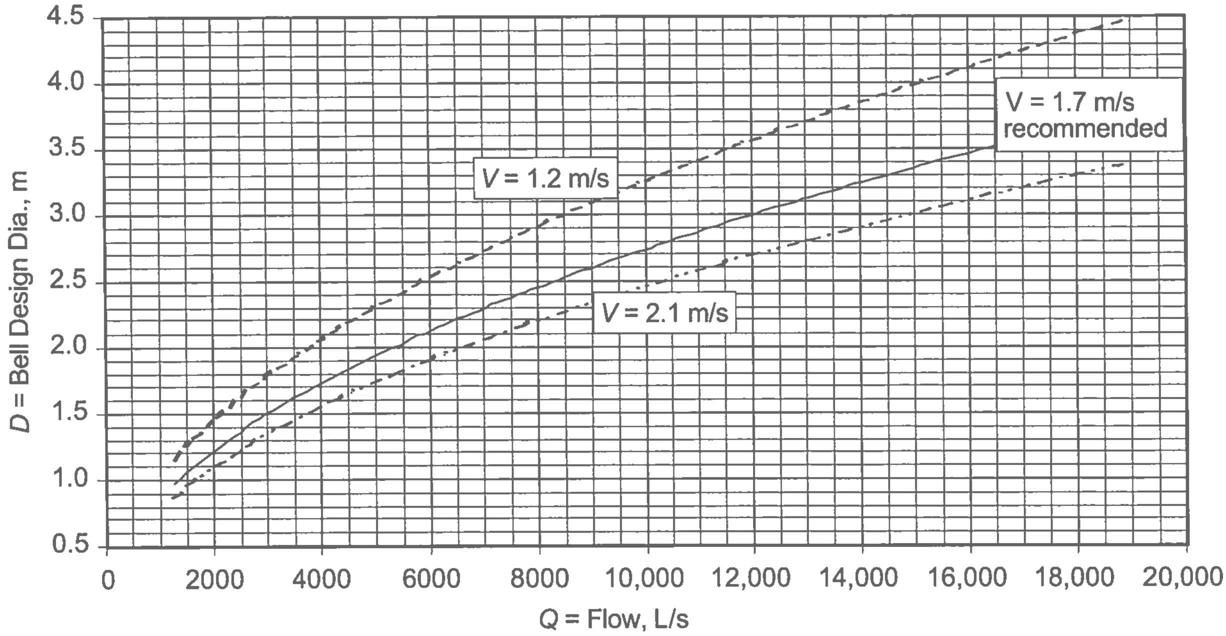
$$D = \left(\frac{Q}{785\,V}\right)^{0.5} \qquad \text{(Eq. 9.8.5.2-1)}$$

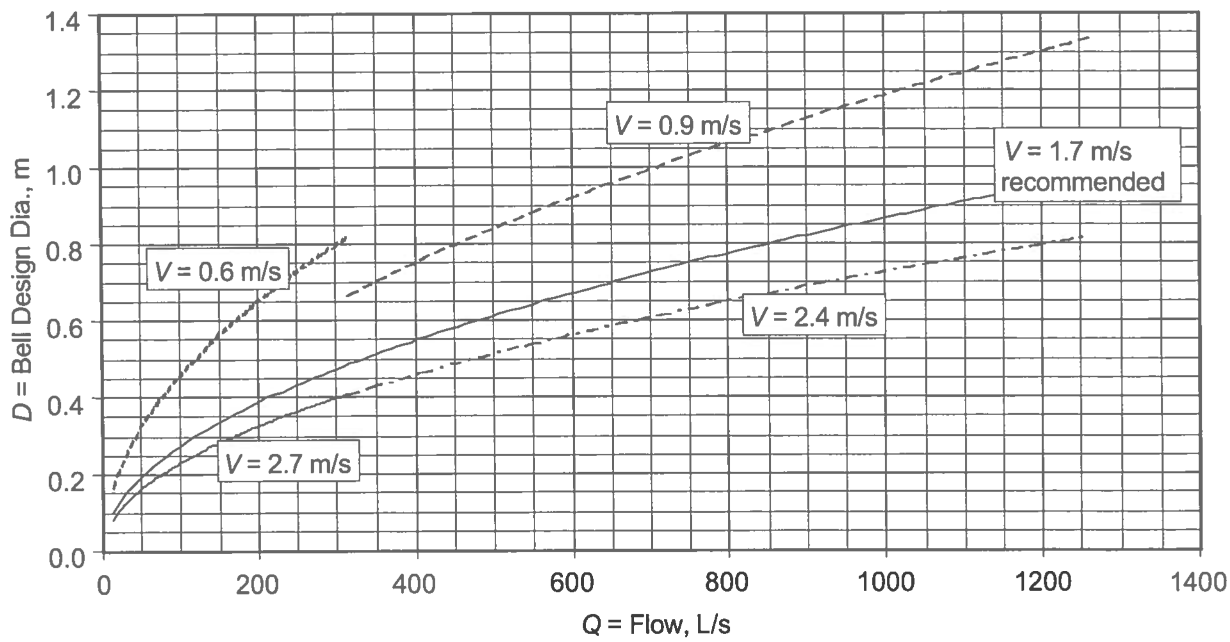
Table 9.8.5.2b — Acceptable velocity ranges for inlet bell diameter *D* (US customary units)

Pump Flow Range Q, gpm	Recommended Inlet Bell Design Velocity, ft/s	Acceptable Velocity Range, ft/s
< 5000	$V = 5.5$	$2 \le V \le 9$
≥ 5000 < 20,000	$V = 5.5$	$3 \le V \le 8$
≥ 20,000	$V = 5.5$	$4 \le V \le 7$

Note: See Figure 9.8.5.2b for corresponding inlet diameters calculated according to

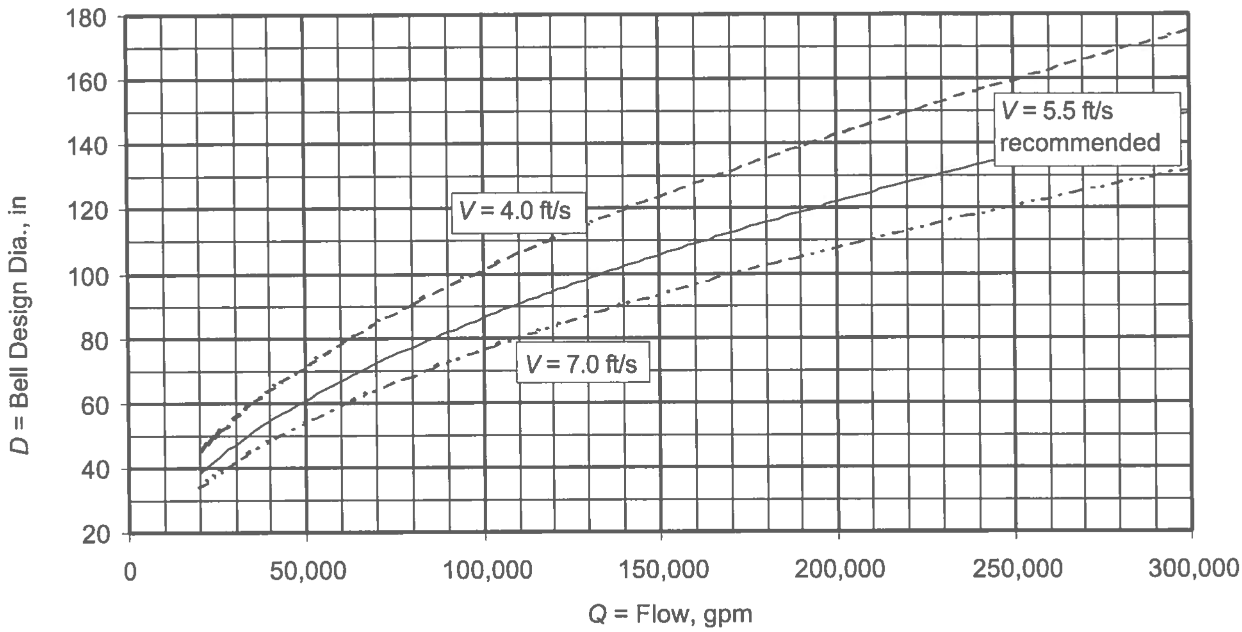
$$D = \left(\frac{0.409\,Q}{V}\right)^{0.5} \qquad \text{(Eq. 9.8.5.2-2)}$$

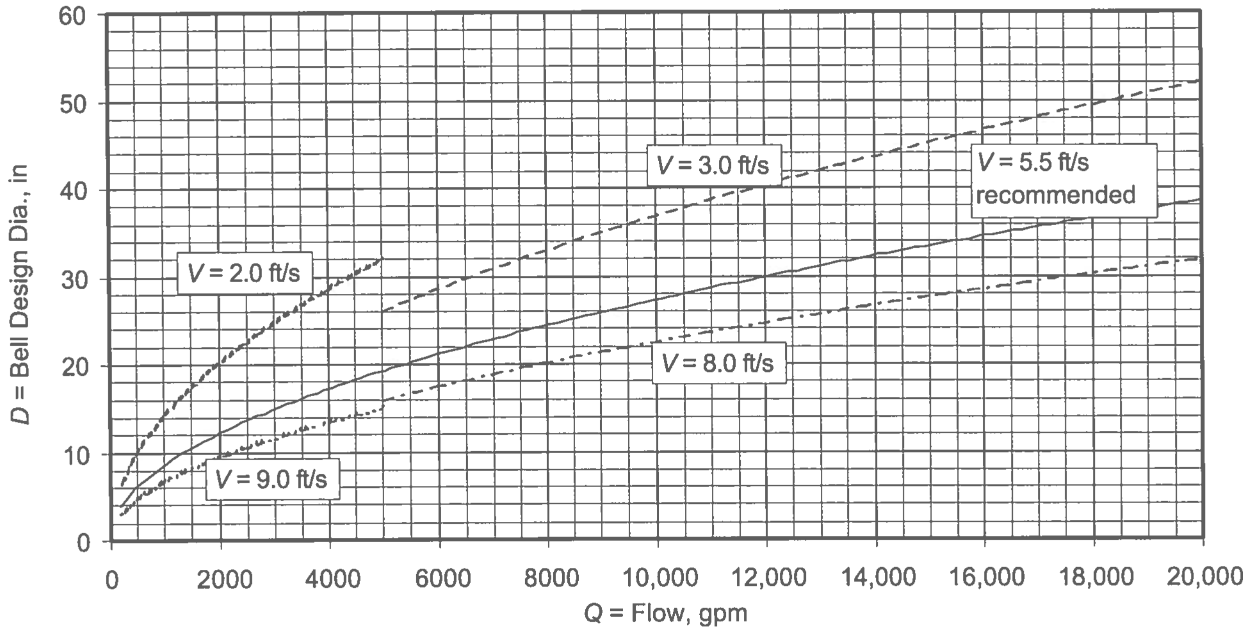




V = Average bell velocity, m/s; Q = flow, L/s; D = outside bell diameter, m; $D = \left(\frac{Q}{785V}\right)^{0.5}$

Figure 9.8.5.2a — Inlet bell design diameter (metric units)





V = Average bell velocity, ft/s; Q = flow, gpm; D = outside bell diameter, in; $D = \left(\frac{0.409\,Q}{V}\right)^{0.5}$

Figure 9.8.5.2b — Inlet bell design diameter (US customary units)

This process will allow the sump design to proceed. When the pump is specified and selected, the outside diameter of its bell (without added horizontal rings or "umbrellas," sometimes used as vortex suppressors) shall fall within the acceptable range to produce an inlet velocity within the limits indicated in Tables 9.8.5.2a and b. An inlet bell diameter within this range will produce a sump geometry that complies with these standards on minimum submergence and sump dimensions.

9.8.6 Required submergence for minimizing surface vortices

9.8.6.1 General

This section concerns the recommended minimum submergence of a pump bell or pipe intake to reduce the probability that strong free surface air core vortices will occur. Submerged vortices are not believed to be related to submergence and are not considered in this section. If a submergence greater than recommended herein is needed to provide the required NPSH for the pump, that greater submergence would govern and must be used.

Approach-flow skewness and the resulting circulation have a controlling influence on free surface vortices in spite of adequate submergence. Due to the inability to predict and quantify approach-flow characteristics for each particular case without resorting to physical model studies, and the lack of available correlation between such characteristics and vortex strength, the recommended minimum submergence given herein is for a reasonably uniform approach flow to the pump suction bell or pipe inlet. Highly nonuniform (skewed) approach flows will require the application of vortex suppression devices (not part of this standard) such as those offered for information in Appendix A. Such devices can be more practical in suppressing vortices than increased submergence.

Even for constant flows, vortices are not steady in position or strength, usually forming and dissipating sporadically. This is due to the random nature by which eddies merge to form coherent circulation around a filament and by which turbulence becomes sufficient in intensity to disrupt the flow pattern. For these reasons, the strength of vortices versus time shall be observed to obtain an average and a maximum vortex type for given conditions, and this process is enhanced by defining a measure of vortex strength, as illustrated in Figure 9.8.4.5a.

9.8.6.2 Controlling parameters

By use of dimensional analysis, it may be shown that a given vortex type, VT, is a function of various dimensionless parameters.

$$VT = f\left(F_D, N_\Gamma, \frac{S}{D}, G\right) \qquad \text{(Eq. 9.8.6.2-1)}$$

Where:

VT = vortex type (strength and persistence)

f = a function

F_D = Froude No. = $\dfrac{V}{(gD)^{0.5}}$

N_Γ = Circulation No., $\Gamma D/Q$, of approach flow

S = Submergence

D = Outside diameter of bell or inside diameter of pipe inlet

G = Geometry

Γ = Circulation ($2\pi r V_t$ for concentric flow about a point with a tangential velocity V_t at radius r)

V = Velocity at inlet $\left(=\frac{4Q}{\pi D^2}\right)$

g = Gravitation acceleration

Q = Flow

For a given geometry and approach flow pattern, the vortex strength would only vary with the remaining parameters, that is

$$VT = f\left(F_D, \frac{S}{D}\right) \qquad \text{(Eq. 9.8.6.2-2)}$$

This formula indicates that a plot of *S/D* versus F_D would contain a family of curves, each representing different values of vortex strength, *VT* (refer to Figure 9.8.4.5a). Selection of one vortex strength of concern, such as a vortex without air entrainment, would yield a unique relationship between *S/D* and F_D, which corresponds to that vortex, all for a given geometry and approach flow pattern (circulation).

For typical intake geometry and relatively uniform approach flow (i.e., low values of the circulation parameter), data and experience suggests that the following recommended relationship between submergence and the Froude number corresponds to an acceptable vortex strength (Hecker, G.E.,1987).

$$\frac{S}{D} = 1.0 + 2.3F_D \qquad \text{(Eq. 9.8.6.2-3)}$$

Where:

S = Submergence above a horizontally oriented inlet plane (vertical inlet pipe) or above the centerline of a vertically oriented inlet plane (horizontal inlet pipe)

D = Diameter of inlet opening (equivalent diameter for noncircular openings, giving the same area as a circular opening)

F_D = Froude No. = $\frac{V}{(gD)^{0.5}}$

V = Velocity at inlet face = Flow/Area

This equation indicates that a minimum of one diameter of submergence must be provided, even at negligible inlet flows or velocities, and that the relative submergence, *S/D*, increases from that value as the inlet velocity increases. This is reasonable, since the inlet velocity (flow) provides the energy to cause a potentially greater vortex strength if the relative submergence were not increased.

The relative submergence would only be constant if the Froude number for various inlets were constant. Information collected by the Hydraulic Institute (not included herein) shows that the average inlet Froude number for bells of typical pump applications is not constant, and that a range of Froude numbers would be possible at a given design flow. Even the restricted range of inlet bell diameters (and velocities) at a given flow recommended in Section 9.8.5 allows some variation in the Froude number. Thus, Equation 9.8.6.2-3 is recommended, rather than a fixed relative submergence.

9.8.6.3 Application considerations

For a given flow, Q, an inlet diameter may be selected in accordance with Section 9.8.5. The recommended minimum submergence for that diameter D would be given by

Metric units:

$$S = 1.0D + 2.3\left[\frac{\left(\frac{Q}{785D^2}\right)}{(gD)^{0.5}}\right]D \qquad \text{(Eq. 9.8.6.3-1)}$$

$$S = D + \frac{\left(\frac{Q}{D^{1.5}}\right)}{1069} \qquad \text{(Eq. 9.8.6.3-2)}$$

Note: S is in meters for g = 9.81 m/s^2, Q in L/s, and D in meters.

US customary units:

$$S = 1.0D + 2.3\left[\frac{\left(12 \times 0.409\frac{Q}{D^2}\right)}{(12gD)^{0.5}}\right]D \text{ or}$$

$$S = D + \frac{0.574Q}{D^{1.5}}$$

Note: S is in inches for g = 32.174 ft/s^2, Q in gpm, and D in inches.

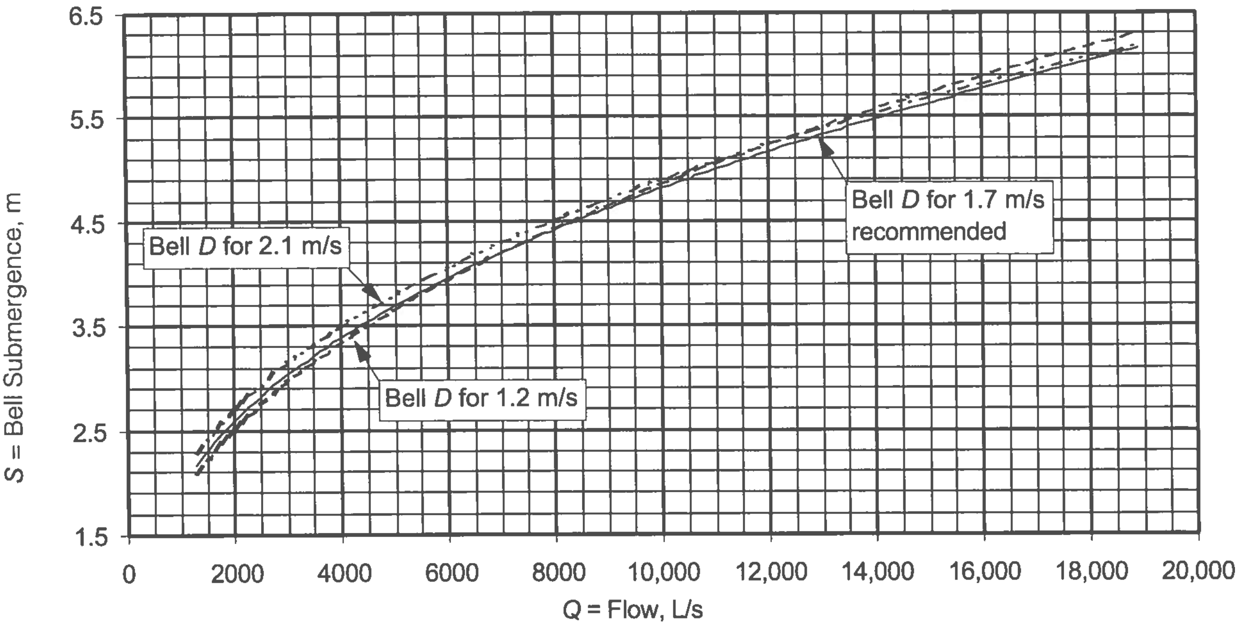
The above illustrates that the actual submergence depends on the selection of D for a given flow. As D increases, the first term causes an increase in submergence, whereas the second term causes a decrease. These opposing trends imply a minimum value of S at some D for a given flow, and differentiating S with respect to D, allows determining that value. However, for the range of recommended bell diameters in Section 9.8.5, the change of S with D for a given flow is minimal, and D for pump bells should be selected based on other considerations.

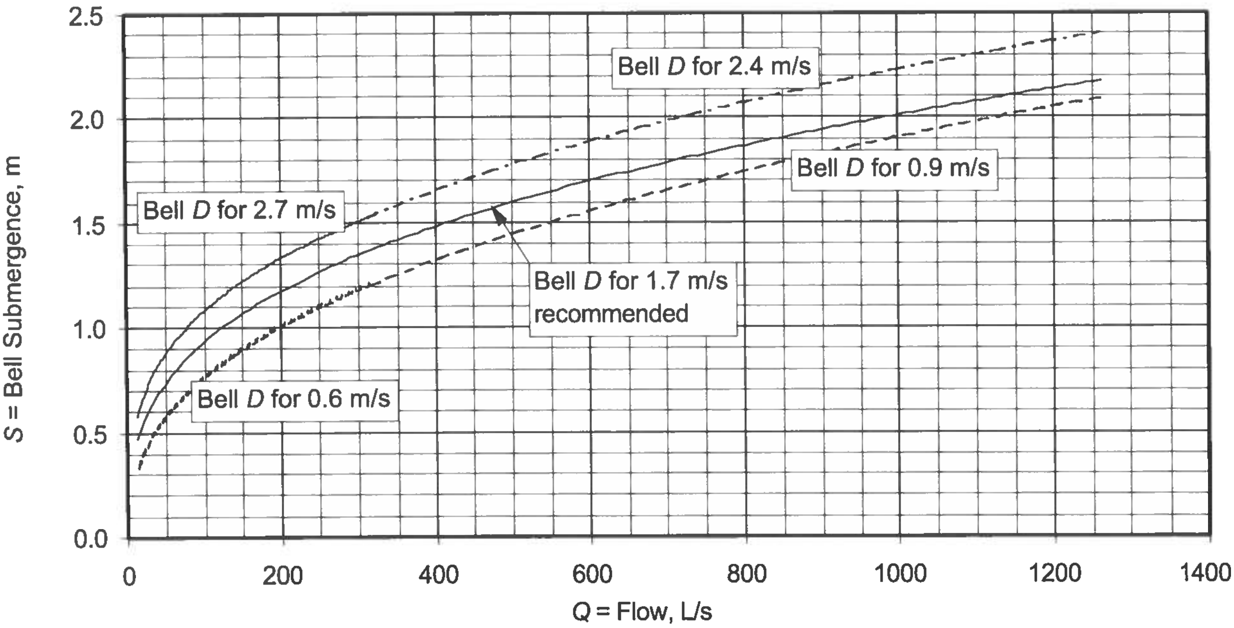
For the inlet bell design diameter recommended in Section 9.8.5, the required minimum submergence for reducing the severity of free surface vortices is shown on Figures 9.8.6.3a and b. These figures also show the recommended minimum submergence for the limits of the bell diameter that comply with these standards, see Figures 9.8.5.2a and b and Tables 9.8.5.2a and b. Due to the small change in submergence, no change in submergence from that calculated with the recommended bell diameter is needed, as long as the final selected bell diameter is within the limits that comply with these standards.

9.8.7 Use of computational fluid dynamics (CFD)

9.8.7.1 General

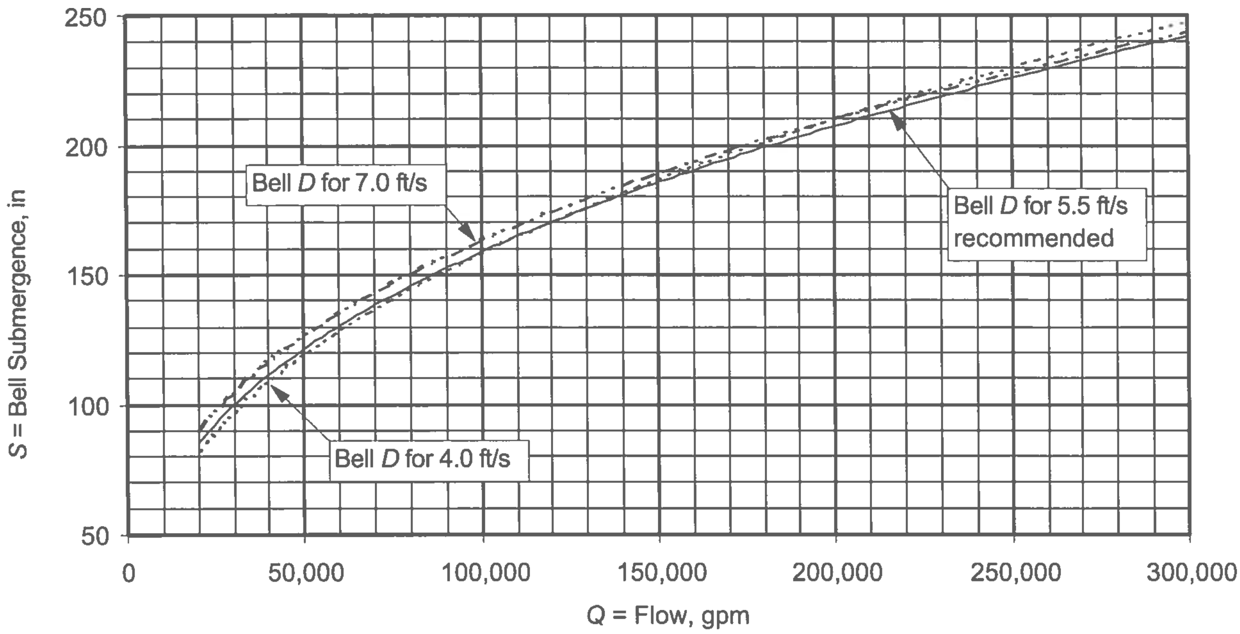
Computational fluid dynamics (CFD) refers to proprietary and commercial computer codes that solve the so-called Reynolds Averaged Navier-Stokes equations for mass, momentum, and heat transfer at many grid points of a three-dimensional flow field. For a given code, there are options for establishing boundary conditions, meshing of the flow domain, and turbulence model selection. Computational speeds and run times are governed by the number of mesh nodes in the numerical model relative to the computer's memory and storage space, processing speed, and the CFD code's efficiency in using computer resources. The potential accuracy of CFD simulations usually increases with finer meshing, but this is limited by the computational power/speed of the CFD code running on a given computer. The outcome of the simulation, therefore, depends on the skill and experience of the modeler as well as the CFD code and the computer being used.

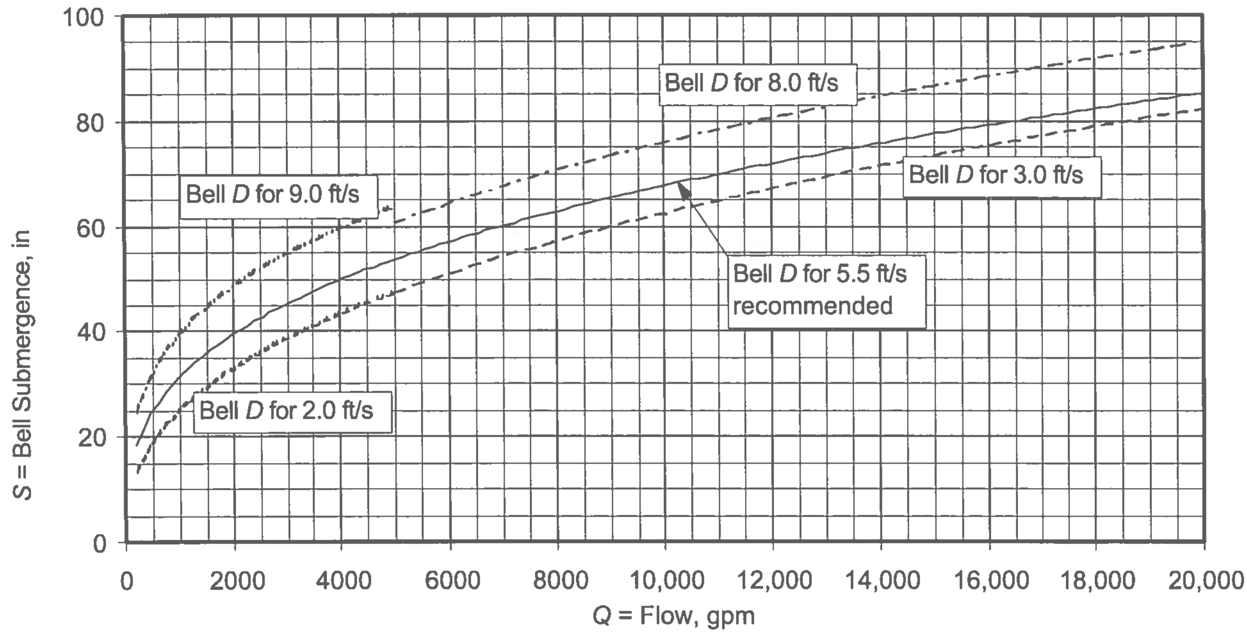




Note: See Figure 9.8.5.2a for corresponding inlet diameters.

Figure 9.8.6.3a — Minimum submergence to minimize free surface vortices (metric units)





Note: See Figure 9.8.5.2b for corresponding inlet diameters.

Figure 9.8.6.3b — Minimum submergence to minimize free surface vortices (US customary units)

9.8.7.2 Simulation methods

When simulating the entire sump and approach geometry, only time average calculations are currently practical, and therefore no fluctuating phenomena or short-term extreme values are usually predicted. Advanced techniques to simulate time-dependent phenomena require further work before they can be standardized. Also, there are practical limitations in predicting highly curvilinear flow patterns, such as swirls and vortices.

9.8.7.3 Correlation of simulation and experimental results

There is a lack of generally available correlations of CFD simulations to experimental results for the complex flow patterns near pump intakes. At the time this standard was prepared, correlations between calculated swirl intensities and free and submerged vortex types were not available. Therefore, CFD shall not be used to predict flow patterns at the pump inlet or to show compliance with the acceptance criteria given in Section 9.8.4.7.

9.8.7.4 Acceptable uses of computational fluid dynamics (CFD)

CFD may be useful in determining the general approach flow to a sump. In particular, the CFD simulation may practically cover a much larger area upstream from the intake than would be possible for a physical model of the scale required to satisfy the minimum Reynolds number given in Section 9.8.4.3. Therefore, the CFD simulations may be used to determine the extent of the physical model and the velocity distribution needed at the model boundary. Useful applications of CFD would include determining whether or not physically modeling a single bay would be adequate and whether or not the predicted upstream velocity distribution (e.g., at the once-through traveling screen) is similar to another intake that operates satisfactorily. CFD simulations may also be used to compare designs, to select a design for testing using a physical model, and to better define the range of variables to be tested.

The advances in CFD indicate that further uses of these computational simulations may be possible in the future and the Hydraulic Institute may consider additional applications of CFD in future revisions of this standard.

9.8.8 Glossary and nomenclature

9.8.8.1 Glossary

Term	Definition
Active Storage	Liquid stored between low and high liquid levels in the wet well and in upstream piping.
Air Core Vortex	A vortex strong enough to form an elongated core of air (see type 6, Figure 9.8.4.5a.
Anti-rotation Baffle	Device used to inhibit the rotation of fluid at or near the suction.
Approach Channel	A structure that directs the flow to the pump.
Approach Pipe	A pipe laid at a gradient sufficient to cause supercritical flow and used to contain a portion of the active storage requirement for a constant speed pump.
Axial Flow (propeller) Pump	High flow rate, low head, high specific speed pump.
Backwall	A vertical surface behind the inlet to a suction fitting.

Term	Definition
Backwall Clearance	The distance between the backwall and the point of closest approach of the suction fitting.
Backwall Splitter	A device formed or fabricated and attached to the backwall that guides the movement of flow at or near a suction.
Baffles	Obstructions arranged to provide a more uniform flow at the approach to a pump or suction inlet.
Barrel Suction	Inlet formed by a "can" encompassing and providing for the suction of a pump.
Bay	A portion of an intake structure configured for the installation of one pump.
Bell	The entrance to an axial flow pump or the flared opening leading to pump inlet piping.
Benching	A type of fillet used to minimize stagnant zones by creating a sloping transition between vertical and horizontal surfaces. Benching is applied between sump walls and the sump bottom, or between the backwall and the sump bottom. It is also referred to as *fillets*, such as *sidewall fillets* and *backwall fillets*.
Cavitation	Formation and implosion of liquid vapor bubbles caused by low local pressures.
Cell	A structure intended to confine the liquid approaching the intake to a pump (*see* Bay).
CFD	*See* Computational Fluid Dynamics.
Check Valve	Piping component used to prevent reverse flow.
Circular Well	A circular suction chamber in plan.
Computational Fluid Dynamics (CFD)	The systematic application of computing systems and computational solution techniques to mathematical models formulated to describe and simulate fluid dynamic phenomena.
Cone	*See* Floor Cone.
Critical Depth	The liquid depth that has the minimum specific energy for a given flow, corresponding to a Froude number equal to 1.
Curtain Wall	A near-vertical plate or wall located in an intake that extends below the normal low liquid level to suppress vortices.
Double Suction Impeller	An impeller provided with a single suction connection that separates and conveys the fluid to two suction areas.
Dry-Pit Suction	Suction from a well that conveys fluid to a pump located in a nonwetted environment.

Term	Definition
Dual Flow Screens	Screening that provides two flow paths for liquid, not in-line with the main flow.
Eddy	A local rotational flow pattern disturbing regular streamlines (a vortex).
End Suction Pump	A pump that has a suction flange coaxial to the impeller shaft and the pump volute is usually not submerged in the sump.
Fillet	A triangular element at the vertex of two surfaces to guide the flow.
Floor Clearance	The distance between the floor and the suction bell or opening.
Floor Cone	A conical fixture placed below the suction between the floor and the suction bell.
Floor Vane	A vertical plate aligned with the approach flow and centered under the suction bell.
Flow Straightener	Any device installed to provide more uniform flow.
Foot Valve	Any device located in the suction of a pump that is designed to keep the line flooded/primed.
Forebay	The region of an intake before individual partitioning of flow into individual suctions or intake bays.
Formed Suction Intake	A shaped suction inlet that directs the flow in a particular pattern into the pump suction.
Free Surface Flow	Open channel or unconfined flow.
Froude Number	A dimensionless grouping of parameters used in flow analysis and modeling that indicates the relative influence of inertial compared to gravitational forces (see Equation 9.8.4.3-1).
Guide Vanes	Devices used in the suction approach that direct the flow in an optimal manner.
Hydraulic Jump	A turbulent sudden increase in liquid depth as the flow decelerates from supercritical to subcritical flow.
Hydrocone	*See* Floor Cone.
Intake	The structure or piping system used to conduct fluid to the pump suction.
Intake Velocity	The average or bulk velocity of the flow in an intake.
Invert	The bottom of a conduit.
Mixer	A mechanical device that produces an axial propeller jet, often used for maintaining suspension of solids-bearing liquids in wet wells and tanks.

Term	Definition
Mixing Nozzles	Nozzles attached to the pump volute or the discharge pipe designed to mix solids in a wet well.
Multiplex Pumping	Pump installations where sets of pumps are used, such as duplex (two) or triplex (three).
NPSHR	The amount of suction head, over vapor pressure, required to prevent more than a 3% loss in total head from the first-stage impeller at a specific flow rate.
Ogee Ramp or Spillway	The gradual change in shape/slope in the floor of an intake, shaped like an elongated letter *S*.
Perforated Baffles	Plate device with specifically sized openings, either vertical or horizontal, applied to produce uniform approach velocity.
Physical Hydraulic Model	A reduced-scale replicate of the geometry that controls approach flow patterns operated according to certain similitude laws for flow, velocity, and time.
Piezometric Head	The sum of pressure head at a point in a body of liquid plus the elevation of the point. In a pressurized conduit, it is seen as the elevation to which a liquid column will rise in a vertical tube if a small hole is drilled in the conduit and connected to the tube. For open-channel flow, it is seen as the elevation of the liquid surface.
Piping Reducer	Any change in pipe size or line area that results in either an increase or decrease in velocity.
Preswirl	Rotation of the flow at the pump suction due to the approach flow patterns.
Pump	A device used to convey fluid from a low energy level to a higher one.
Pump Column	Part of the pump assembly that both connects the pump to the discharge head and nozzle and conveys fluid into the system.
Pump Suction Bell	A part of the pump that provides an opening to convey flow into the suction eye of the impeller.
Rectangular Wet Well	Any wet well in which pumps are arranged along a wall opposite the influent conduit. The shape may be square, rectangular, or trapezoidal.
Reynolds Number	A dimensionless grouping of parameters used in flow analysis and modeling that indicates the relative influence of inertial compared to viscous forces (see Section 9.8.4.3).
Scale	The ratio between geometric characteristics of the physical model and prototype.

Term	Definition
Scale Effect	The impact of reduced scale on the applicability of test results to a full-scale prototype.
Sediment	Settleable materials suspended in the flow.
Septicity	A condition in which stagnant domestic sewage turns septic due to a lack of oxygen.
Sequent Depth	The depth of liquid following a hydraulic jump.
Snoring	The condition that occurs when a pump is allowed to draw down the liquid level very close to the pump's inlet. Snoring refers to the gurgling sound associated with continuous air entrainment.
Solids	Material suspended in the liquid.
Specific Energy	For open-channel flow, the energy per unit weight of liquid relative to the channel bottom. For a channel with small slope and uniform velocity distribution, it is the sum of the depth and the velocity head of the liquid. For closed-conduit flow, the energy per unit weight of liquid relative to a vertical datum, and is the sum of piezometric head and velocity head.
Specific Speed	An index of pump performance (developed total head) at the pump's best efficiency point (BEP) rate of flow, with the maximum diameter impeller, and at a given rotative speed. For more information refer to ANSI/HI 2.1-2.2 *Rotodynamic (Vertical) Pumps for Nomenclature and Definitions.*
Soffit	Inside top of a conduit.
Submergence	The height of liquid level over the suction bell or pipe inlet.
Submersible Pump	A close-coupled pump and drive unit designed for operation while immersed in the pumped liquid.
Suction Bell Diameter	Overall OD of the suction connection at the entrance to a suction.
Suction Head	Pressure available at the pump suction, usually positive if the liquid level is at a higher elevation than the pump suction.
Suction Lift	Negative pressure at the pump suction, usually a result of the liquid level being at a lower elevation than the pump suction.
Suction Scoop	A device added to the suction to change the direction of flow. *See* Formed Suction Intake.

Term	Definition
Suction Strainer	A device located at the inlet to either protect the pump or provide flow stability at the suction.
Sump	A pump intake basin or wet well. *See* Forebay.
Swirl	Rotation of fluid around its mean, axial flow direction.
Swirl Angle	The angle formed by the axial and tangential (circumferential) components of a velocity vector (see Equation 9.8.4.5-1).
Swirl Meter	A device with four flat vanes of zero pitch used to determine the extent of rotation in otherwise axial flow.
Trench Intake	An intake design that aligns the pump suctions in-line with but below the inflow. A type of forebay.
Turning Vanes	Devices applied to the suction to alter the direction of flow.
Unconfined Suction/ Intake	Suction in a free-flow field with no lateral physical boundaries.
Unitized Intake	A multiple pump intake with partitioned pump bays.
Vane	*See* Floor Vane.
Volute	The pump casing for a centrifugal type of pump, typically spiral or circular in shape.
Vortex	A well-defined swirling flow core from either the free surface or from a solid boundary to the pump inlet (see Figures 9.8.4.5a and b).
Vortex, Free Surface	A vortex that terminates at the free surface of a flow field.
Vortex, Subsurface	A vortex that terminates on the floor or sidewalls of an intake.
Vortex Suppressor	A fixed or floating device used to help minimize surface or subsurface vortices.
Wall Clearance	Dimensional distance between the suction and the nearest vertical surface.
Wastewater	Description of fluid that typically carries suspended waste material from domestic or industrial sources.
Weber Number	A dimensionless grouping of parameters used in flow analysis and modeling that indicates the relative influence of inertial compared to surface tension forces (see Section 9.8.4.3).
Wet-Pit Suction	A suction with the pump fully wetted.

Term	Definition
Wet Well	A pump intake basin or sump having a confined liquid volume with a free liquid surface designed to hold liquid in temporary storage to even out variations between inflow and outflow. *See* Forebay.

9.8.8.2 Nomenclature

Table 9.8.8.2 — Nomenclature

Sym.	Definition	Reference Location
A	Distance from the pump inlet centerline to the intake structure entrance	Fig. 9.8.2.1.4a, Table 9.8.2.1.4a
A_e	Empty area	Table C.1, Table C.2
A_t	Total area	Table C.1, Table C.2
a	Length of constricted bay section near the pump inlet	Fig. 9.8.2.1.4b, Table 9.8.2.1.4a
B	Distance from the backwall to the pump inlet bell centerline	Fig. 9.8.2.1.4a and b, Table 9.8.2.1.4a
C	Distance between the inlet bell and floor	Fig. 9.8.2.1.4a and b, Table 9.8.2.1.4a
C_b	Inlet bell or volute clearance for circular pump stations	9.8.2.3.2.1, 9.8.2.3.2.4, Fig. 9.8.2.3.1a, b, c, d, e, f
C_f	Floor clearance on circular pump stations	9.8.2.3.2.1, 9.8.2.3.2.2, Fig. 9.8.2.3.1a, b, c, d, e, f
C_w	Wall clearance on circular pump stations	9.8.2.3.2.1, 9.8.2.3.2.3, Fig. 9.8.2.3.1a, b, c, d, e, f
D	Inlet bell diameter or inlet bell design diameter (may also refer to pipe inside diameter if a pipe is used instead of a bell inlet)	9.8.2.1.3, 9.8.2.1.4, Eq. 9.8.2.1.4-1, Eq. 9.8.2.1.4-2, Fig. 9.8.2.1.4a, Fig. 9.8.2.1.4b, Table 9.8.2.1.4a, Table 9.8.2.1.4b, 9.8.2.4.7, 9.8.2.4.8, 9.8.2.4.9, Fig. 9.8.2.6.5, 9.8.2.7.2, 9.8.2.7.4, 9.8.3.2.3.1, 9.8.3.2.3.2, Fig. 9.8.3.2.2, 9.8.3.3.3, Fig. 9.8.3.4.4, 9.8.3.4.4.1, 9.8.4.3, 9.8.5, Table 9.8.5.2a, b, Fig. 9.8.5.2a, b, 9.8.6.2, Eq. 9.8.6-1, Fig. 9.8.6.3, Fig. A.10, Fig. A.11
D	Tank outlet fitting inside diameter	9.8.2.5.4, Fig. 9.8.2.5.5, 9.8.2.5.5
D_1	Vertical can riser inside diameter	Fig. 9.8.2.6.4
D_1	Can inside diameter	Fig. 9.8.2.6.5, Fig. G.1
D_b	Inlet bell or volute diameter	9.8.2.3.2.1, 9.8.2.3.2.2, 9.8.2.3.2.3, 9.8.2.3.2.4, 9.8.2.3.2.6, Fig. 9.8.2.3.1a, b, c, d, e, f
D_e	Diameter of circle with area equivalent to rectangular area at FSI entrance	9.8.2.2.3, Eq. 9.8.2.2.3-1
D_M	Well motor cooling shroud diameter	Fig. G.1

Table 9.8.8.2 — Nomenclature (*continued*)

Sym.	Definition	Reference Location
D_p	Inside diameter of approach pipe	C.2, C.4, Table C.1, Table C.2
D_s	Sump diameter	9.8.2.3.2.1, 9.8.2.3.2.5, Fig. 9.8.2.3.1a, Fig. 9.8.2.3.1b
d	Diameter at outlet of formed suction intake	Fig. 9.8.2.2.2, Type 10 formed suction intake
d	Diameter of the pipe at the swirl meter	Eq. 9.8.4.5-1, Fig. 9.8.2.3.1b
EGL	Energy grade line	C.4.3
F	Froude number (general)	9.8.4.3, Eq. 9.8.4.3-1
F_D	Froude number (calculated at diameter D)	Fig. 9.8.2.1.4a, Eq. 9.8.2.1.4-1, Eq. 9.8.2.1.4-2, Table 9.8.2.1.4a, 9.8.2.1.4, 9.8.2.2.3, Eq. 9.8.2.2.3-1, 9.8.2.5.4, 9.8.2.7.4, Fig. 9.8.3.2.2, Eq. 9.8.6.2-1, 9.8.6.2
F_r	Froude number ratio, F_m/F_p	9.8.4.3, Eq. 9.8.4.3-2
F_m	Froude number of physical model	9.8.4.3, Eq. 9.8.4.3-2
F_p	Froude number of prototype	9.8.4.3, Eq. 9.8.4.3-2
G	Geometry	9.8.6.2
g	Acceleration of gravity	9.8.2.1.4, Eq. 9.8.2.1.4-1, 9.8.2.5.4, 9.8.4.3, Eq. 9.8.4.3-1, 9.8.6.2, 9.8.6.3
H	Minimum liquid depth	Fig. 9.8.2.1.4a and b, Fig. 9.8.2.1.4b, Table 9.8.2.1.4a
H_f	Height of FSI	Fig. 9.8.2.2.2, 9.8.2.2.3, Fig. 9.8.2.4.1b
h	Minimum height of constricted bay section near the pump	Fig. 9.8.2.1.4b, Table 9.8.2.1.4a
L	A characteristic length (usually bell diameter or submergence)	9.8.4.3, Eq. 9.8.4.3-1
L_r	Geometric scale of physical model	Eq. 9.8.4.3-3, Eq. 9.8.4.3-4, Eq. 9.8.4.3-5
L_v	Characteristic length of a cubic cage-type vortex suppressor	Fig. A.13
N_Γ	Circulation number	9.8.6.2
n	Revolutions/second of the swirl meter	Eq. 9.8.4.5-1
n	Manning's number	C.4.2, Tables C.1 and C.2
Q	Flow	Table 9.8.5.2a and b, Fig. 9.8.5.2a and b, 9.8.6.2, 9.8.7.3, Fig. 9.8.6.3a and b
Q	Inflow into sump	B.2, Eq. B.1-1, Eq. B.1-2, Eq. B.1-3, Eq. B.1-4
Q_m	Flow scale in physical model	Eq. 9.8.4.3-4
Q_p	Flow scale in prototype	Eq. 9.8.4.3-4

Table 9.8.8.2 — Nomenclature (*continued*)

Sym.	Definition	Reference Location
Q_r	Flow scale ratio, physical model/prototype	Eq. 9.8.4.3-4
R	Reynolds number	9.8.4.3
r	Radius of curvature	Fig. 9.8.2.2.2, 9.8.3.2.3, Fig. 9.8.3.2.2
r	Radius of tangential velocity component	9.8.6.2
S	Minimum submergence depth	Fig. 9.8.2.1.4a, Eq. 9.8.2.1-2, 9.8.2.1.4, Table 9.8.2.1.4a, 9.8.2.2.3, Fig. 9.8.2.2.2, 9.8.2.3.2.1, Fig. 9.8.2.3.1a, Fig. 9.8.2.3.1b, c, d, e, f, Fig. 9.8.2.4.1b, 9.8.2.5.4, Fig. 9.8.2.5.4, Fig. 9.8.2.5.4, Fig. 9.8.2.7, 9.8.2.7.4, Fig. 9.8.3.2.2, Fig. 9.8.3.4.4, 9.8.6.3, 9.8.6.2, Eq. 9.8.6.2-1, Fig. 9.8.6.3a and b
T	Total cycle time in seconds	B.2, Eq. B.2-1, Eq. B.2-2, Eq. B.2-3, Eq. B.2-5
T_m	Time scale of physical model	Eq. 9.8.4.3-5
T_p	Time scale of prototype	Eq. 9.8.4.3-5
T_r	Time scale ratio, physical model/prototype	Eq. 9.8.4.3-5
u	Average axial velocity (such as in the suction bell)	9.8.4.3, Eq. 9.8.4.3-1
u	Average axial velocity at the swirl meter	Eq. 9.8.4.3-6
V	Velocity	Eq. 9.8.2.1.4-1, 9.8.2.1.4, 9.8.2.2.3, 9.8.2.5.4, 9.8.2.5.5, Fig. 9.8.2.5.5, Fig. 9.8.2.6.4, 9.8.2.7.4, 9.8.5, Table 9.8.5.2a, b, Fig. 9.8.5.2a, b, 9.8.6.2
Vol	Active sump volume	B.2, Eq. B.2-1, Eq. B.2-2, Eq. B.2-3, Eq. B.2-5
V_c	Cross-flow velocity	Fig. 9.8.2.1.4a, Table 9.8.2.1.4a
V_m	Velocity scale in physical model	Eq. 9.8.4.3-3
V_p	Velocity scale in prototype	Eq. 9.8.4.3-3
V_r	Velocity scale ratio, physical model/prototype	Eq. 9.8.4.3-3, Eq. 9.8.4.3-4, Eq. 9.8.4.3-5
V_t	Tangential velocity	9.8.6.2
V_x	Pump bay velocity	Fig. 9.8.2.1.4a, Table 9.8.2.1.4a
VT	Vortex type	9.8.6.2
We	Weber number	9.8.4.3
W	Pump bay entrance width	Fig. 9.8.2.1.4a, Table 9.8.2.1.4a, Fig. 9.8.2.1.4b
W	Width of FSI	9.8.2.2.3, Fig. 9.8.2.2.2, Fig. 9.8.2.4.1b
w	Constricted bay width near the pump	Fig. 9.8.2.1.4b, Table 9.8.2.1.4a

Table 9.8.8.2 — Nomenclature (*continued*)

Sym.	Definition	Reference Location
X	Pump bay length	Fig. 9.8.2.1.4a, Table 9.8.2.1.4a
Y	Distance from pump inlet bell centerline to traveling screen	9.8.2.1.4, Fig. 9.8.2.1.4a,Table 9.8.2.1.4a
y	Depth	Table C.1, Table C.2
Z_1	Distance from pump inlet bell centerline to diverging walls	Fig. 9.8.2.1.4a, Table 9.8.2.1.4a
Z_2	Distance from pump inlet bell centerline to sloping floor	Fig. 9.8.2.1.4a, Table 9.8.2.1.4a
α	Angle of floor slope	Fig. 9.8.2.1.4a, Table 9.8.2.1.4a
β	Angle of wall divergence	9.8.2.1.4, Fig. 9.8.2.1.4a,Table 9.8.2.1.4a
ε	Angle of sidewall of trench	Fig. 9.8.3.2.2
f	A function	9.8.6.2
ρ	Liquid density	9.8.4.3
Γ	Circulation of the flow	9.8.4.3, 9.8.6.2
ν	Kinematic viscosity of the liquid	9.8.4.3
θ	Swirl angle	Eq. 9.8.4.5-1
σ	Surface tension of liquid/air interface	9.8.4.3
ϕ	Angle of divergence from constricted area to bay walls	Fig. 9.8.2.1.4b, Table 9.8.2.1.4a

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Appendices

These appendices are not part of this standard, but are presented to help the user in considering factors beyond the standard sump design.

Refer to Section 9.8.1 of the standard, which allows for an intake designed to a geometry other than presented in the standard and such as contained in these appendices, to be deemed to comply with the standard, if the intake is tested by prototype testing or a physical model study performed in accordance with Section 9.8.4, and the test results comply with the acceptance criteria in Section 9.8.4.6.

Requirements for a physical model study are given in Section 9.8.4.

Appendix A

Remedial measures for problem intakes

Information in this appendix is not part of this standard, but is presented to help the user in considering factors beyond the standard sump design.

Refer to Section 9.8.1 of the standard, which allows for an intake designed to a geometry other than presented in the standard and such as contained in these appendices, to be deemed to comply with the standard, if the intake is tested by prototype testing or a physical model study performed in accordance with Section 9.8.4, and the test results comply with the acceptance criteria in Section 9.8.4.6

Requirements for physical hydraulic model study are given in Section 9.8.4.

A.1 Introduction

The material presented in Appendix A is provided for the convenience of the intake design engineer in correcting unfavorable hydraulic conditions of existing intakes. None of the remedial measures described herein are part of the standard intake design recommendations provided in Section 9.8. A portion of the material in Appendix A transmits general experience and knowledge gained over many years of improving the hydraulics of intake structures, and such educational material may not include the specific recommendations appropriate for a standard. Corrections described herein have been effective in the past, but may or may not result in a significant improvement in performance characteristics for a given set of site-specific conditions. Other remedial fixes not provided herein may also be effective, and a physical model test is needed to verify whether or not a given remedial design feature results in acceptable flow conditions. This is particularly true because adding a remedial feature to solve one flow problem may have detrimental effects on other flow phenomena of concern.

Appendix A concentrates on rectangular intakes for clear liquids, but the basic principles can be applied to other types of intakes. The material is organized by the general type of hydraulic problem in an upstream to downstream direction, because proper upstream flow conditions minimize downstream remedial changes.

A.2 Approach flow patterns

The characteristics of the flow approaching an intake structure is one of the foremost considerations for the designer. Unfortunately, local ambient flow patterns are often difficult and expensive to characterize. Even if known, conditions are often unique, frequently complex, so it is difficult to predict the effects of a given set of flow conditions upstream from an intake structure on flow patterns in the immediate vicinity of a pump suction.

When determining direction and distribution of flow at the entrance to a pump intake structure, the following must be considered:

- The orientation of the structure relative to the body of supply liquid
- Whether the structure is recessed from, flush with, or protrudes beyond the boundaries of the body of supply liquid
- Strength of currents in the body of supply liquid perpendicular to the direction of approach to the pumps
- The number of pumps required and their anticipated operating combinations

Velocity profiles entering pump bays can be skewed, regardless of whether or not crosscurrents are present. Several typical approach flow conditions are shown in Figure A.1 for rectangular intake structures withdrawing flow from both moving bodies of liquid and stationary reservoirs. Figure A.2 shows several typical approach flow conditions for different combinations of pumps operating in a single intake structure.

The ideal conditions, and the assumptions on which the geometry and dimensions recommended for rectangular intake structures in this section are based, are that the structure draws flow so that there are negligible ambient currents (cross-flows) in the vicinity of the intake structure that create asymmetrical flow patterns approaching any of the pumps, and the structure is oriented so that the boundary is symmetrical with respect to the centerline of the structure. As a general guide, cross-flow velocities are significant if they exceed 50% of the pump bay entrance velocity. Recommendations (based on a physical model study) for analyzing departures from the ideal condition are given in Section 9.8.4.

A.2.1 Open versus partitioned structures

If multiple pumps are installed in a single intake structure, dividing walls placed between the pumps result in more favorable flow conditions than found in open sumps. Open sumps, with no dividing walls, have been used with varying levels of success, but adverse flow patterns can frequently occur if dividing walls are not used. The trench-type intake structure, described in Sections 9.8.2.4 and 9.8.3.2, is a type of open sump that is an exception. Open sumps are particularly susceptible to crosscurrents and nonuniform approach flow patterns. Even if approach flow at the entrance to the structure is uniform, open sumps result in nonuniform flow patterns approaching some of the pumps when operating pumps are arranged asymmetrically with respect to the centerline of the intake structure. This situation can occur when various combinations of pumps are operating or if the intake structure is designed to accommodate additional pumps at some future date. Figure A.3 is an example of flow approaching the pumps in both a partitioned structure and an open sump, both operating at partial flow rate.

The example facilities contain four units with two of the four operating. In both structures, flow is withdrawn from a reservoir with no velocity component perpendicular to the longitudinal centerline of the intake structures. In the partitioned structure, flow enters the bay of pump 1 fairly uniformly. It enters the bay containing pump 2 nonuniformly, with a separation area near the right sidewall. However, the length of the bay relative to its width channels the flow and allows it to become more uniform as it approaches the pump. In Figure A.3, example ii, the dashed line at the wing walls shows a rounded entrance configuration that minimizes flow separation near the entrance to the outer pump bays.

In open sumps (Figure A.3, example i), flow may enter the structure uniformly with respect to the centerline of the structure. However, since the location of the two operating pumps is not symmetrical with the respect to the centerline of the structure, flow separates from the right wall of the structure and approaches pump 2 with a tangential velocity component, greatly increasing the probability of unacceptable levels of preswirl.

If all four pumps in the open sump were to operate simultaneously, approach flow would be reasonably uniform, but other adverse phenomena could be present. For example, when two adjacent pumps are operating simultaneously, submerged vortices frequently form, connecting both pumps.

A.3 Controlling cross-flow

If cross-flow is present (i.e., if the pump station is withdrawing flow from the bank of a canal or stream), trash racks with elongated bars can provide some assistance in distribution flow as it enters the pump bay, but if the flow profile is skewed when it enters the trash rack, it will be skewed as it exits. To be effective in guiding flow, trash racks must be placed flush with the upstream edges of the pump bay dividing walls. In this example the trash rack must be vertical or match the incline of the entrance. Both trash racks and dividing walls must be in line with the stream bank contour. Trash racks recessed from the entrance to pump bays, and through-flow traveling screens have a negligible flow-straightening effect (see Figure A.4).

Partially clogged trash racks or screens can create severely skewed flow profiles. If the application is such that screens or trash racks are susceptible to clogging, they must be inspected and cleaned as frequently as necessary to prevent adverse effects on flow patterns.

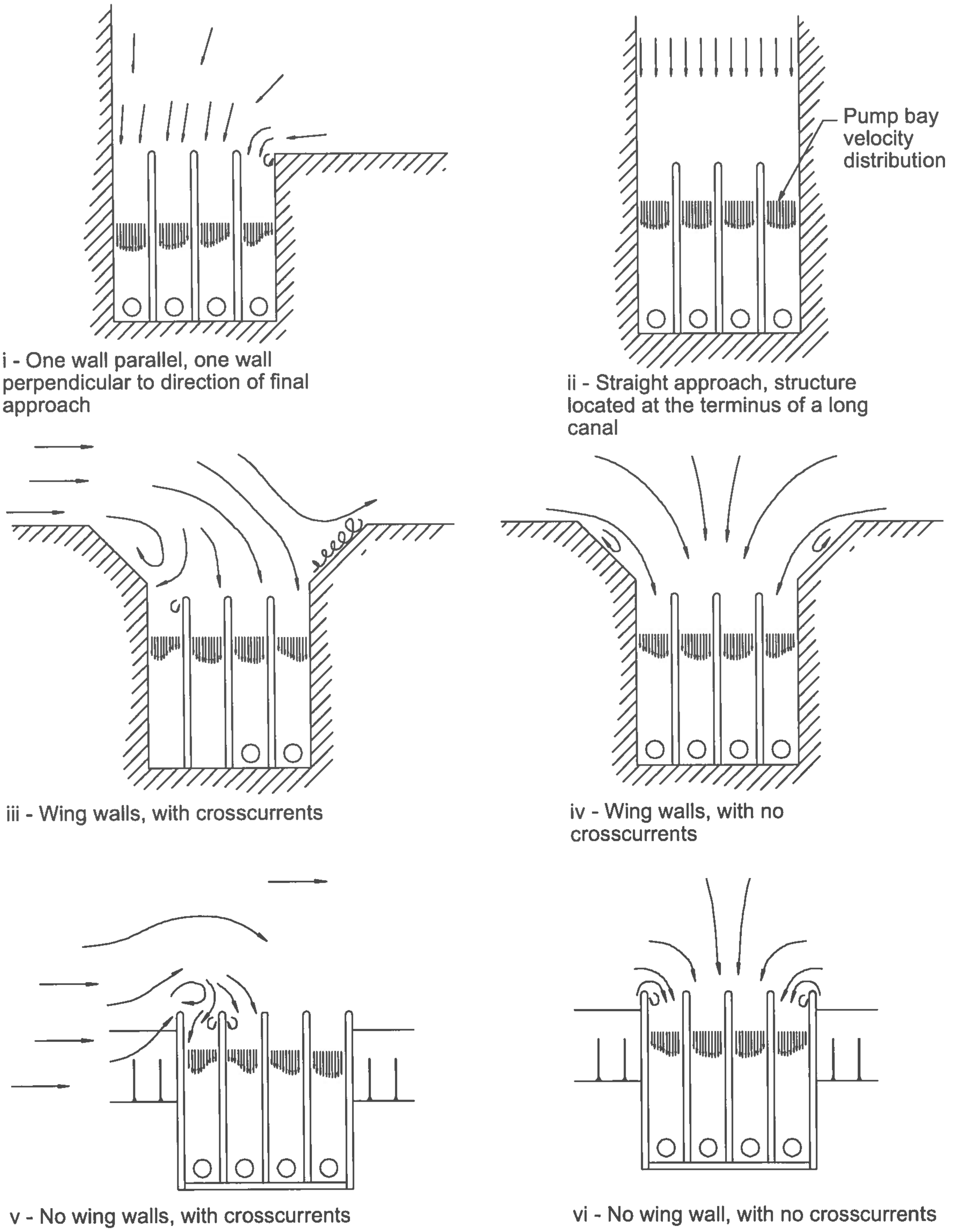


Figure A.1 — Examples of approach flow conditions at intake structures and the resulting effect on velocity, all pumps operating

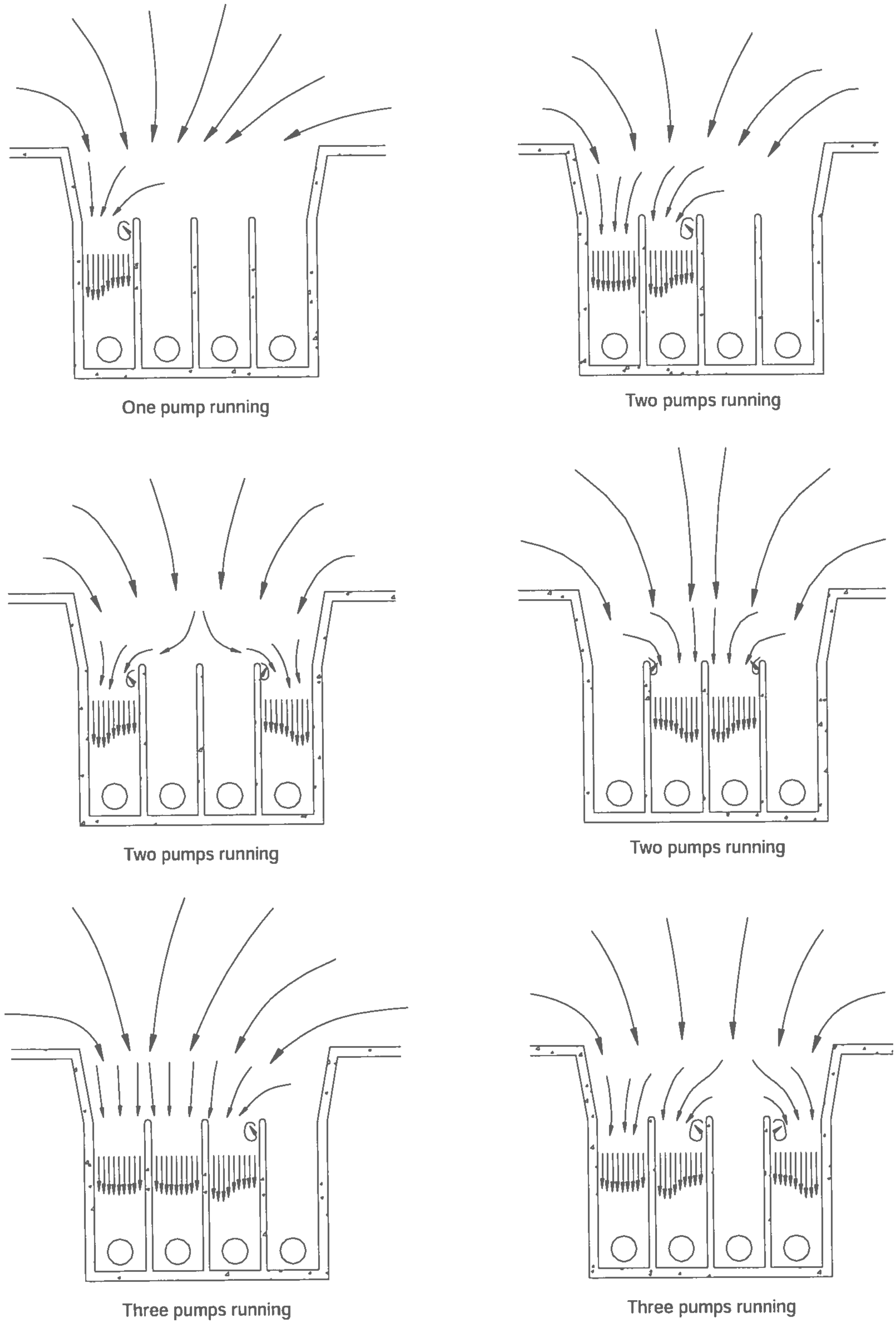
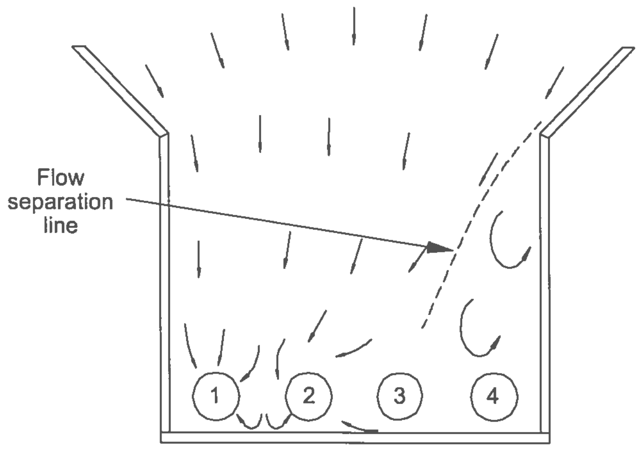
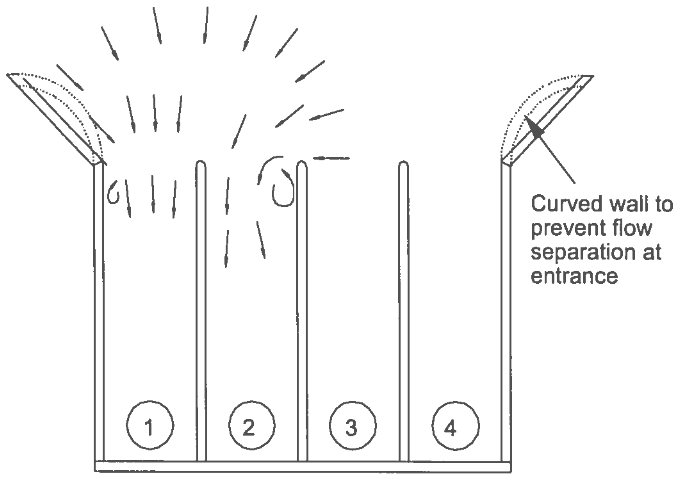


Figure A.2 — Examples of pump approach flow patterns for various combinations of operating pumps



i - Open sump, pumps 1 & 2 operating,
illustrating problem flow patterns



ii - Partitioned sump, pumps 1 & 2 operating,
less likely to result in flow problems

Figure A.3 — Comparison of flow patterns in open and partitioned sumps

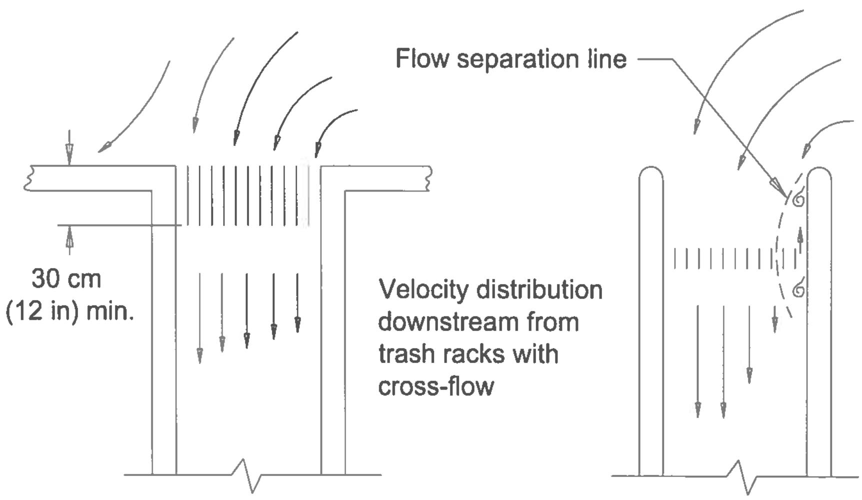


Figure A.4 — Effect of trash rack design and location on velocity distribution entering pump bay

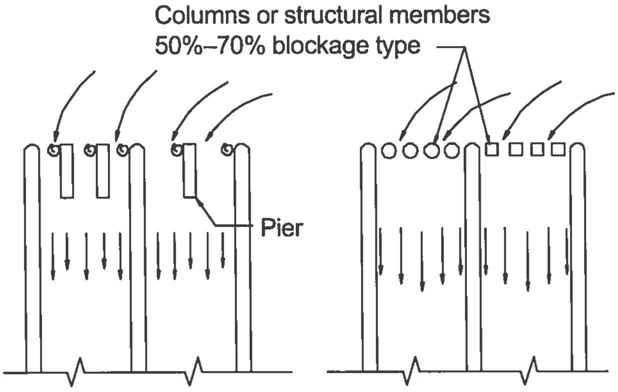


Figure A.5 — Flow-guiding devices at entrance to individual pump bays

Two other flow-straightening devices for minimizing cross-flow effects at bay entrances are shown in Figure A.5. One or two large guide piers or plates per bay help turn the flow. Although distinct flow separation eddies occur at each pier, the eddies are smaller than the single flow separation (eddy) that would occur along one bay wall. Alternatively, a number of smaller columns or structural members may be placed at the bay entrance, and these are effective in both turning and creating more uniform velocity by inducing a head loss across the column array.

A.4 Expanding concentrated flows

Two methods for correcting flow disturbances generated by expansion of a concentrated flow are described below.

A.4.1 Free surface approach

In some installations, site conditions dictate that the approach flow channel or conduit, although in line with the sump axis, is much smaller than the sump width. To avoid concentrated flow and large eddies, the sidewalls approaching the pump bays must gradually diverge, and flow baffles of varying geometry or guide vanes may be used to spread the flow at a divergence angle greater than otherwise possible. Figure A.6 shows possible corrective measures.

The flow leaving a dual entry flow screen requires baffling to break up and laterally distribute the concentrated flow prior to reaching the pump, and one possible arrangement is shown in Figure A.7.

If measures are not taken to mitigate the effects these screens have on flow patterns (see Figure A.8), then the jet exiting the center of these screens will attach to one wall or the other, and will result in highly nonuniform flow for an indefinite distance down the channel. The nonuniform flow creates excessive swirl at the pump. The screen exit must be placed a minimum distance of six bell diameters, 6*D*, (see Section 9.8.2.1.3) from the pumps. However, this distance is only a general guideline for initial layouts of structures, with final design to be developed with the aid of a physical model study.

A.4.2 Closed conduit approach

Flow may be provided to rectangular intake structures through a conduit. When multiple pumps are installed perpendicularly to the influent conduit, the flow pattern improves and approach velocities decrease if the sump walls diverge gradually from the point of influent toward the pump bays. Maintaining a small angle divergence of each wall from the influent conduit minimizes the difficulty in spreading the flow uniformly. A series of flow distribution baffles may be installed to dissipate the energy of the entering flow and force a diverging and more uniform flow pattern approaching the pumps. A typical approach flow pattern in a wet well with a conduit approach, with and without diverging sidewalls and flow distribution baffles, is shown in Figure A.6.

If a conduit approach is required and there is no room for gradually diverging sidewalls, velocities in the conduit entering the sump may need to be limited, such as by adding expansion pieces to the downstream end of the

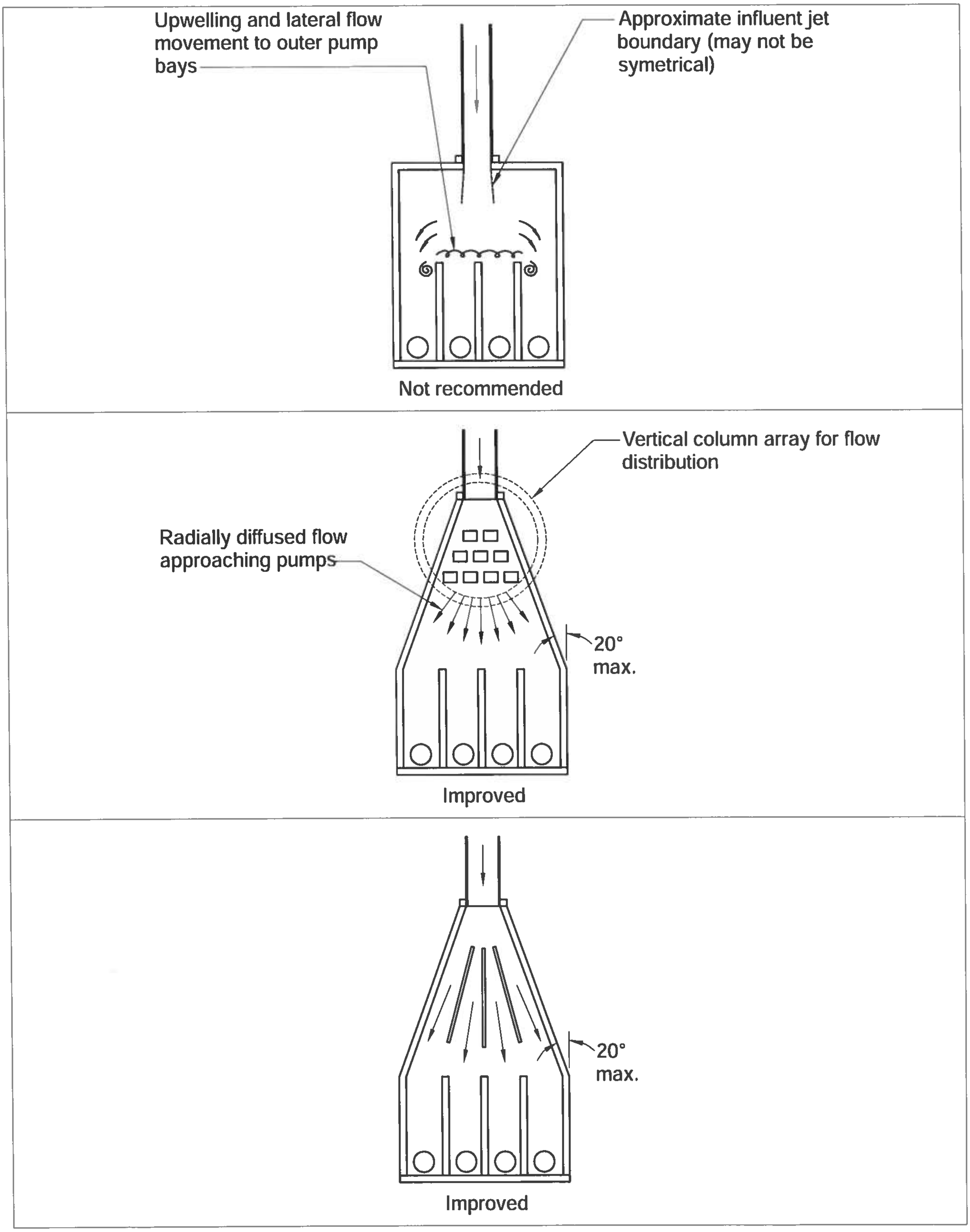


Figure A.6 — Concentrated influent configuration, with and without flow distribution devices

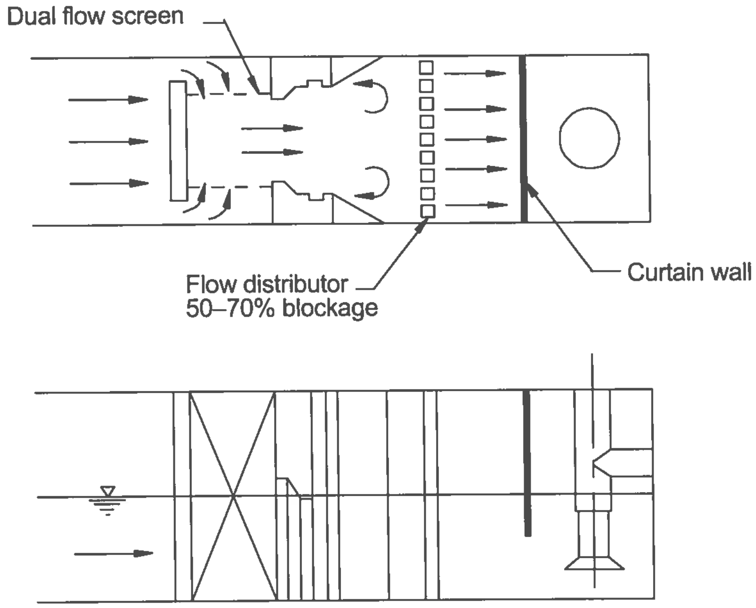


Figure A.7 — Baffling to improve flow pattern downstream from dual flow screen. Note: Physical model study required.

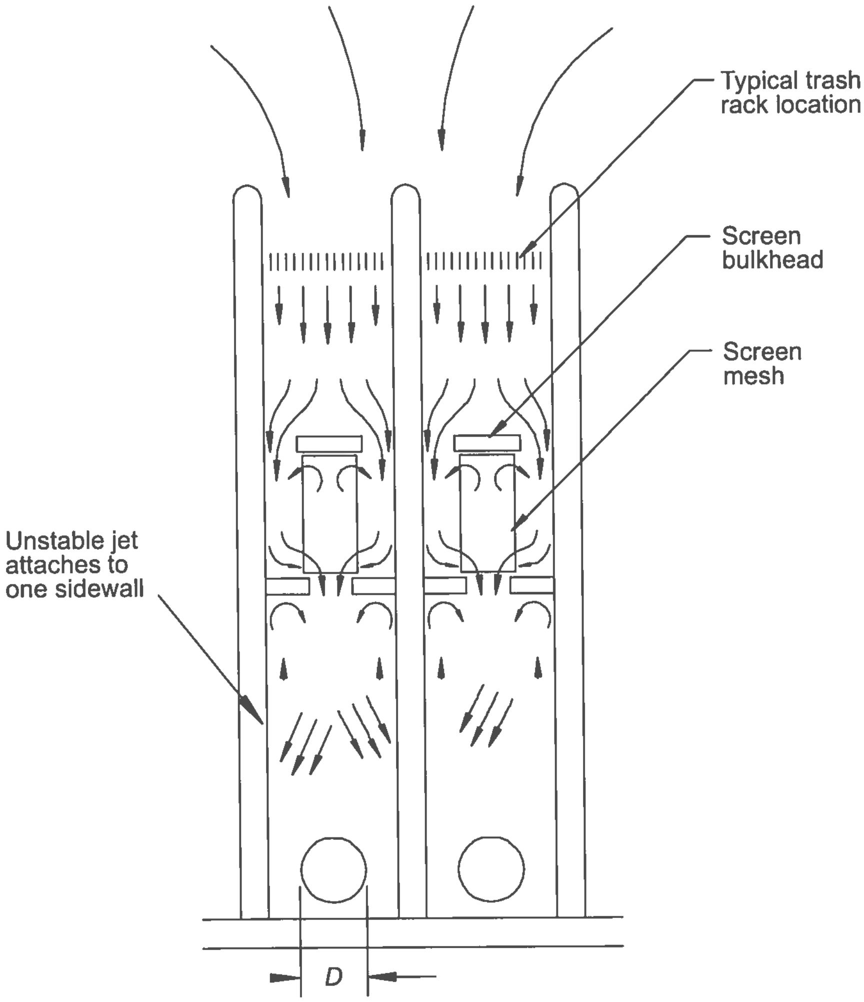


Figure A.8 — Typical flow pattern through a dual flow screen

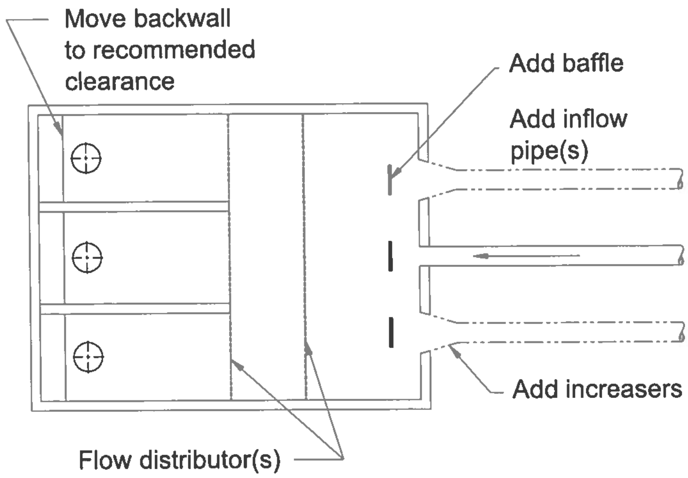


Figure A.9 — Improvements to approach flow without diverging sump walls

conduit. In addition to the features described above, a baffle may be needed near the influent point of the conduit(s) to dissipate the energy from the entering jet and spread the flow toward the pump bays. Increasing the number of inflow lines together with a flow distributor across the sump and/or each bay may provide an adequate distribution to the pump bays, see Figure A.9.

The trench-type wet well described in Section 9.8.2.4 is an alternate arrangement, where the pumps are positioned in line with the approach pipe.

A.5 Pump inlet disturbances

A.5.1 Free surface vortices

Surface vortices may be reduced with increasing depth of submergence of the pump bells. However, there are also situations where increasing depth has negligible effects or even increases surface vortex formation due to stagnant and therefore unstable liquid. Surface vortices are also highly dependent on approach flow patterns and the stability of these patterns, as well as on the inlet Froude number. The above situation complicates the establishment of a minimum depth of submergence as a definitive measure against vortices. To achieve a higher degree of certainty that objectionable surface vortices do not form, modifications can be made to intake structures to allow operation at practical depths of submergence.

Many manufacturers offer a corrective option for a suction bell by adding a suction umbrella. Suction umbrellas are formed pieces, usually horizontally oriented flat rings or plates attached to the pump bell or supported by radial vanes to the sump floor. They minimize free surface vortices, prevent entrainment of air, and reduce the minimum submergence and disturbances at pump inlet. The bell diameter increase effectively reduces the velocities at the periphery of the inlet. Suction umbrella diameter can be up to the full width *W* of the pump inlet bay.

The most effective use of suction umbrellas is for pumps in drainage or other pump-down services where the minimum liquid depth occurs at the end of the pumping cycle. For more information, see Dicmas, J.L., *Vertical Turbine, Mixed Flow, and Propeller Pumps*, McGraw-Hill Book Co.

Curtain walls, such as shown in Figures A.10 and A.12, create a horizontal shear plane that is perpendicular to the vertical axis of rotation of surface vortices, and prevent the vortices from continuing into the inlet.

Vertical curtain walls have been used with success and are easier to construct than sloping curtain walls. However, the abrupt changes in flow direction caused by vertical walls can create surface vortices in the upstream corners of those walls. If the curtain walls are placed at about 45 degrees from the vertical, then all flow near the surface is deflected downwards and surface vortices are minimized. Curtain walls also assist in spreading poorly-distributed flow.

Horizontal gratings may also be used to suppress free surface vortices when pumping clear liquids. Standard floor grating 38 mm (1.5 in) deep or greater, or a specially constructed "egg-crate" type grating may be effective. At the low liquid level, the top of the grating should be submerged about 150 mm (6 in). As a temporary measure, floating rafts of various types may be used to suppress surface vortices.

A.5.2 Subsurface vortices

The geometry of boundaries in the immediate vicinity of the pump bells is one of the more critical aspects of successful intake structure design. It is in this area that the most complicated flow patterns exist and flow must make the most changes in direction, while maintaining a constant acceleration into the pump bells to prevent local flow separation, turbulence, and submerged vortex formation. Pump bell clearance from the floor and walls is an integral part of the design. A sampling of various devices to address subsurface vortices are shown in Figure A.11. These and other measures may be used individually or in combination to reduce the probability of flow separation and submerged vortices.

A.5.3 Preswirl

Whether or not preswirl exists to an objectionable extent is governed primarily by the approach flow distribution. A sufficiently laterally skewed approach flow causes rotation around the pump bell, in spite of the local features. Such rotation causes flow over the center splitter (Figure A.11, example viii) and potentially produces a submerged vortex emanating from the flow separation at the center splitter. A cone on the floor would not cause such a submerged vortex problem, but the cone would also not help to control residual preswirl.

The most effective way of reducing preswirl is to establish a relatively uniform approach flow within each pump bay by using the baffling schemes discussed in Sections A.2 to A.4 above. Final reductions in swirl may be achieved near the pump bell by installing a vertical splitter along the backwall, in line and directly behind the pump column, by providing a horizontal (sloping) floor splitter under the bell as shown in Figure A.11 and perhaps by using a submerged curtain wall (shown in Figures A.10 and A.12) across the bay width, close to the upstream side of the pump. This wall, if a few bell diameters high off the floor, has the effect of turning all the flow downward, similar to that in a circular "can" arrangement, and the basic change in flow pattern may reduce preswirl and other undesirable hydraulic phenomena.

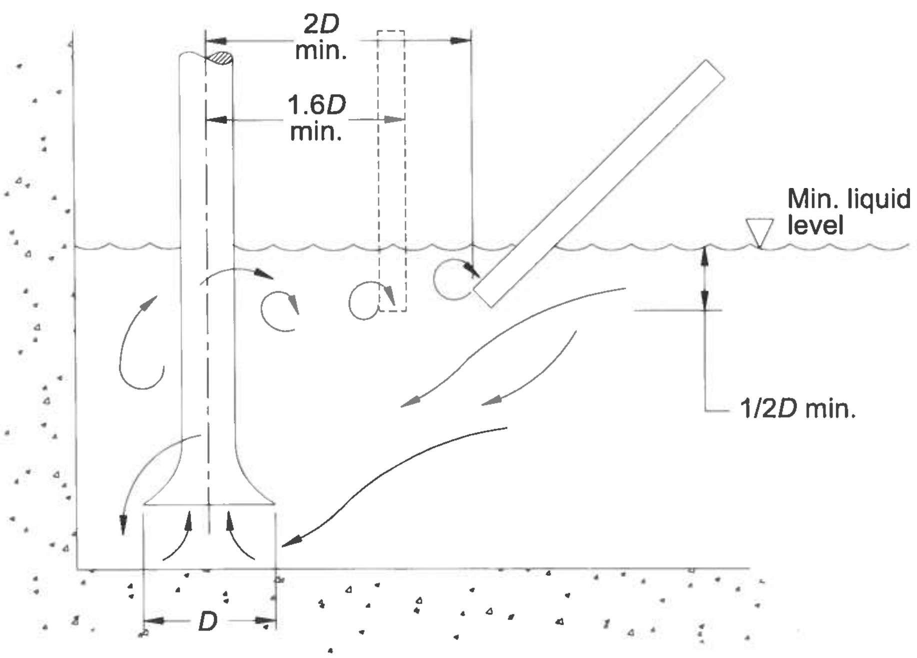


Figure A.10 — Elevation view of a curtain wall for minimizing surface vortices

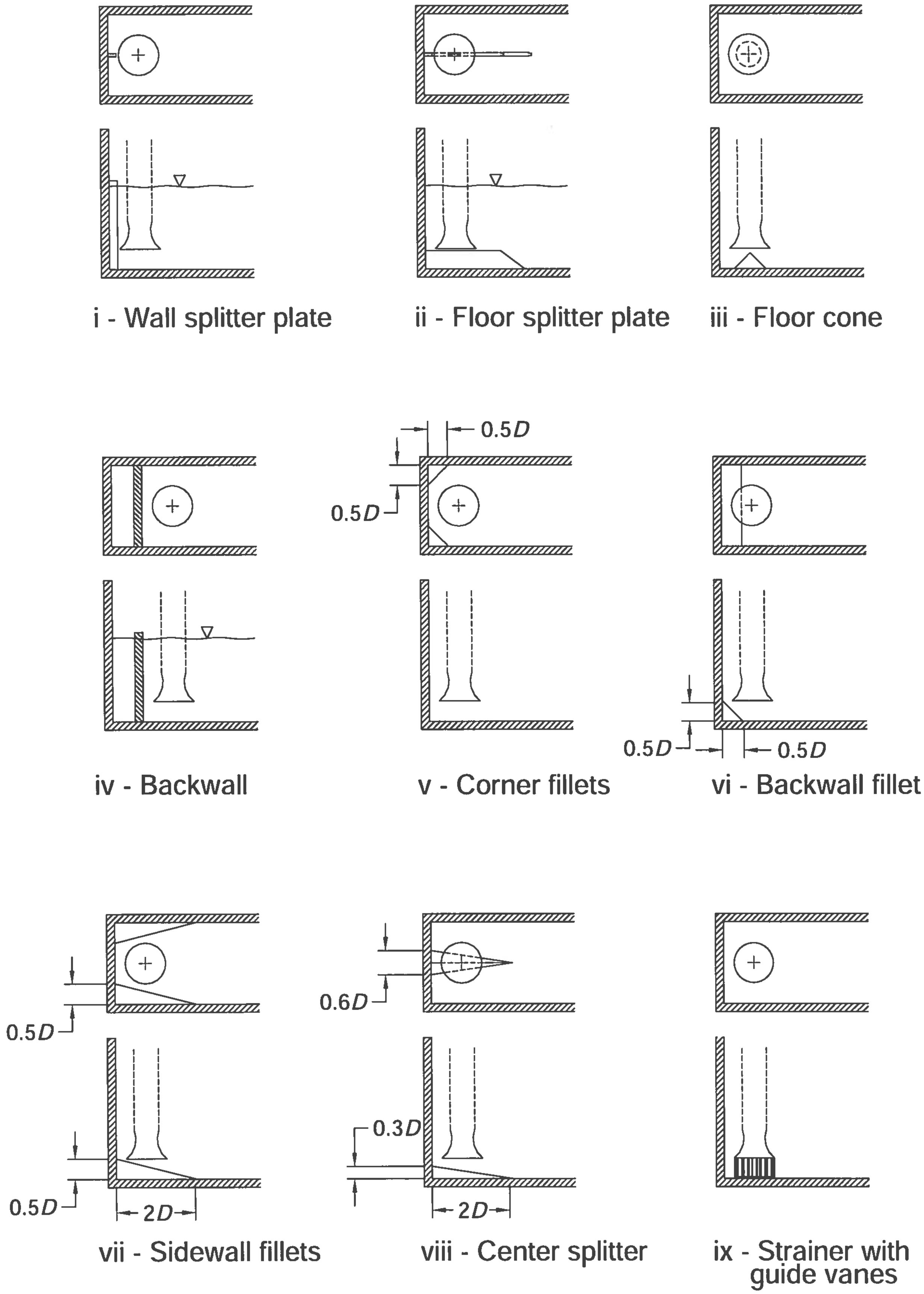


Figure A.11 — Methods to reduce subsurface vortices (examples i – ix)

A.5.4 Velocities in pump bell throat

A relatively uniform velocity distribution occurs at the pump bell throat if the flow enters the bell essentially radially, without preswirl or local flow disturbances such as vortices or eddies caused by local flow separation. Therefore, all of the above-described flow control devices, starting with providing a uniform approach flow and including local antivortex measures near the bell, may be needed to achieve the desired uniformity of velocities.

Alternatively, a properly shaped formed suction intake (FSI) may be provided, as discussed in Section 9.8.2.2. Model tests have shown that the FSI provides the desired uniformity of velocity at the bell throat for reasonable flow patterns approaching the FSI.

A.6 Deviations from standard dimensions

When a rectangular intake does not conform to the standard dimensions of Figure 9.8.2.1.4a, it may be helpful to understand some of the observed effects of such deviations. Designs not built in accordance with the standard dimensions may or may not operate satisfactorily depending on a variety of factors. Designers may have reasons for selecting nonstandard intake dimensions, in particular, when there exists a successful experience record with the nonstandard configuration, or certain specific physical constraints or performance objectives are to be satisfied.

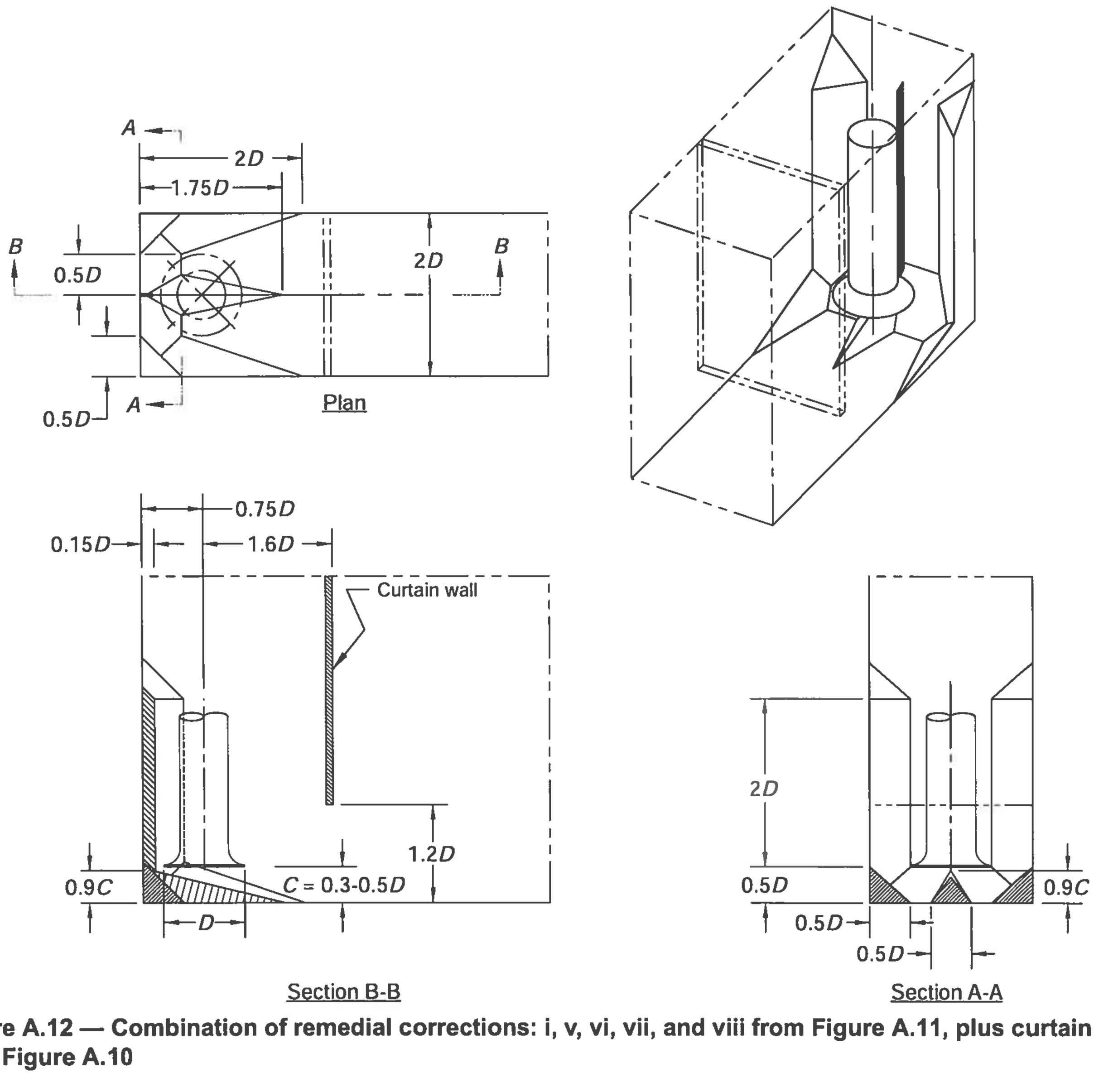


Figure A.12 — Combination of remedial corrections: i, v, vi, vii, and viii from Figure A.11, plus curtain wall from Figure A.10

Depending on the degree of deviation from standard dimensions, adverse flow patterns can result, which may be difficult to correct. Deviations from the standard intake dimensions are in general not recommended, but when used, the design should be evaluated by a physical model study.

Narrower bay widths W are possible, particularly when the suction bell diameter (D) is sized generously, and the resultant pump bay velocity V_x does not exceed the recommended maximum. An advantage of a narrower bay width is the increased level of turbulence, which can help suppress the formation of surface vortices. On the other hand, the increased velocities in the vicinity of the pump intake can intensify subsurface vortices and velocity distortions around the suction bell. Bay widths with values W as low as $1.5D$ have been made to work satisfactorily.

The clearance between the bell and sump floor C is typically near $0.5D$. Occasionally there may exist a need for a design outside of the recommended range $0.3D \leq C \geq 0.5D$. Values of $C > 0.5D$ are possible, but would likely require one or more methods to reduce subsurface vortices (Figure A.11). When flow velocities surrounding the bell are relatively uniform, or when a generously sized bell diameter with low peripheral velocity is used, a clearance $C < 0.3D$ may be possible, for instance, when designing for pumping down to low liquid levels. Clearance values of $C < 0.25D$ may result in a decelerating velocity with attendant flow instabilities under the bell.

The recommended backwall clearance B is $0.75D$. Pumps fitted with generously sized bells or umbrella skirts may justify a reduced backwall clearance simply based on the clearance geometry and flow velocities surrounding the impeller eye. The potential benefit of minimizing dimension B is to lessen the tendency of surface vortices to form behind the pump column, but this may come at the expense of a persistent subsurface vortex under the bell from the backwall. A reduced B dimension may also make it difficult to achieve an acceptable velocity distribution at the impeller eye. Axial flow and higher specific speed mixed flow pumps may suffer measurable head loss as the value of clearance B is reduced. Values of B greater than $0.75D$ increase the tendency for surface vortexing and create stagnant areas behind the bell where subsurface vortices may develop.

A.7 Tanks - pump suction

A.7.1 General

Undesirable flow conditions may be created at the pump inlet suction outlet in the tank depending on the inflow–outflow arrangement in a storage tank, whether or not the tank inflow is operating while the pump suction outlet is operating, and whether or not there are flow obstructions in the tank. Even if only the pump suction outlet is operating and there are no flow obstructions in the tank, the nonuniform approach flow to the pump suction outlet may cause pre-swirl and vortices.

The main problem is usually entrainment of air (or other tank gases) due to free surface vortices or aeration of the tank contents from free fall of the tank inflow, as this air may collect in the piping (causing air binding) or cause degradation of pump performance.

Preventing the formation of free surface vortices at tank outlets to pumps allows the tank to be drawn to lower levels than would otherwise be possible. This benefit requires the use of various antivortex devices at the inlet. Some common types of such devices are shown in Figure A.13.

A.7.2 Vertical tank, simultaneous inflow and outflow

Inflows to a tank can cause significant disruption of the outflow due to aeration caused by a free-falling inflow. The best way to suppress this is with either a submerged inlet pipe or a J-pipe; see Figure A.14. The submerged inlet pipe should extend down to the bottom tangent of the tank. A J-pipe can be a good alternate if the tank is tall. The end of the J-pipe should be within one pipe diameter of the tank wall. If the inflow is corrosive or contains solids, an impingement plate may be needed. Another alternative is to put the inflow nozzle low on the side of the tank, so the inflow is always submerged.

To suppress vortex formation in order to decrease the minimum submergence to less than that calculated in Section 9.8.2.5.4, use a horizontal baffle as shown in Figure A.13, example 1, or a cross as shown in Figure A.13, example 2 or 3.

Flat-bottom tanks typically have side outlet nozzles. To decrease the minimum submergence below that calculated in Section 9.8.2.5.4, use a horizontal baffle as shown in Figure A.13, example 4. The baffle radius should be at least equal to *S*, as calculated in Section 9.8.2.5.4 and shown in Figure A.14. The baffle should be 2*D* above the nozzle centerline.

A.7.3 Horizontal tank, simultaneous inflow and outflow

Inflows to a horizontal tank can cause significant disruption of the outflow due to aeration caused by a free-falling inflow. The two design features that suppress outflow disruption are having the inflow and outflow nozzles at opposite ends of the tank and using a submerged inlet pipe; see Figure A.14. The submerged inlet pipe should extend down to within four pipe diameters of the tank bottom.

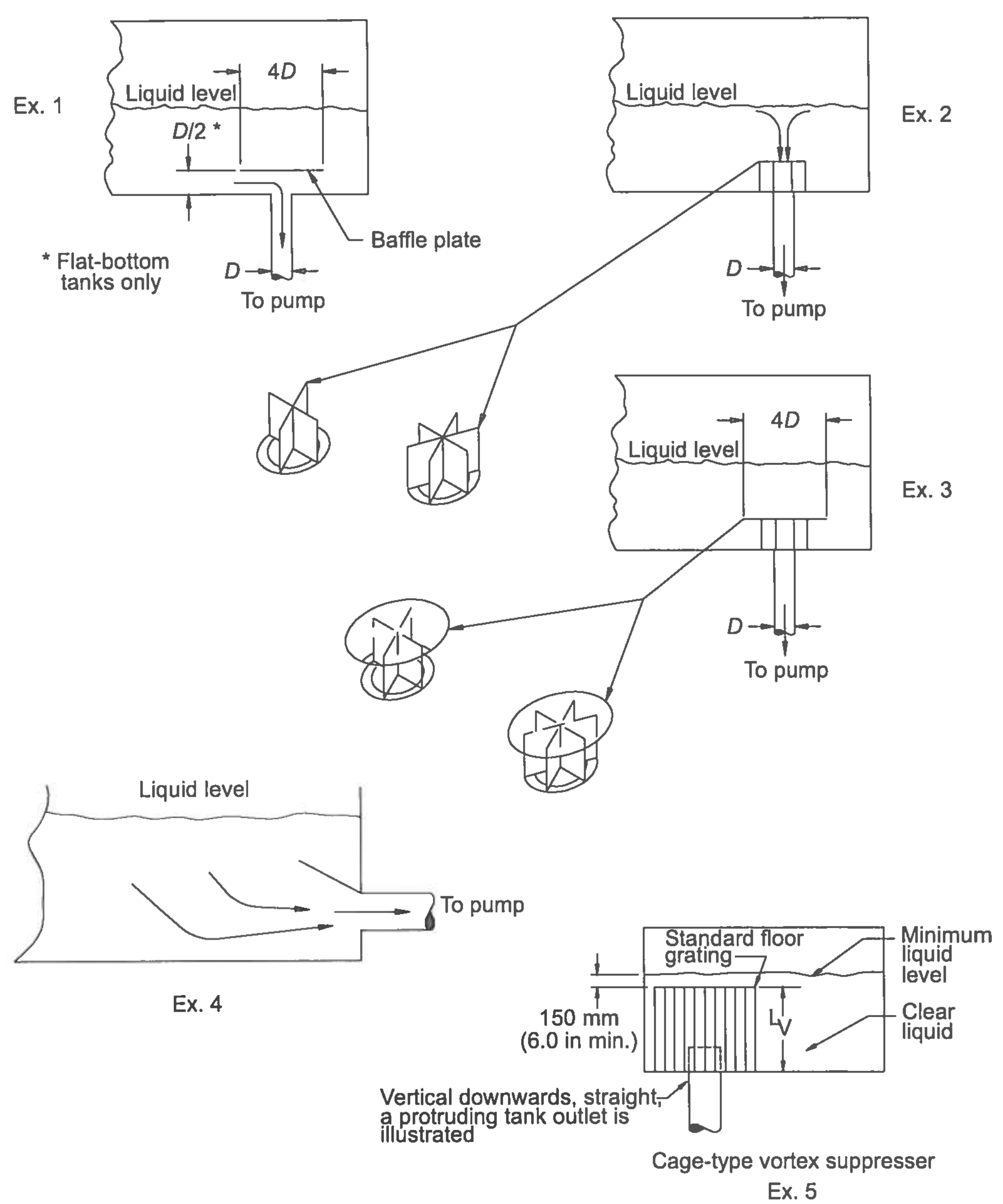


Figure A.13 — Tank antivortex devices

To suppress vortex formation in order to decrease the minimum submergence to less than that calculated in Section 9.8.2.5.4, use a horizontal baffle as shown in Figure A.13, example 1, or a cross as shown in Figure A.13, examples 2 or 3.

As an alternative, a cage-type vortex suppressor may be used, as illustrated in Figure A.13, example 5. The cubic cage may be made of standard 38-mm (1.5-in) deep (or deeper) floor grating (or its equivalent). The length, width, and height of the cubic cage, each with a characteristic length termed *Lv* should be about three inlet pipe diameters, and the top of the cage should be submerged about 150 mm (6 in) below the minimum liquid level. Noncubic cage shapes are also effective if the upper (horizontal) grating is at least three inlet pipe diameters on each side and is also submerged 150 mm (6 in) below the minimum liquid level. A single horizontal grating meeting these guidelines may also be effective. Tests on such cage-type vortex suppressors have demonstrated their capability to reduce air entrainment to nearly zero even under adverse approach flow conditions (Padmanabhan, 1982). However, it may be noted that the minimum submergence from the tank floor is dictated by the vertical cage dimension plus the needed 150-mm (6-in) submergence above the top of the cage.

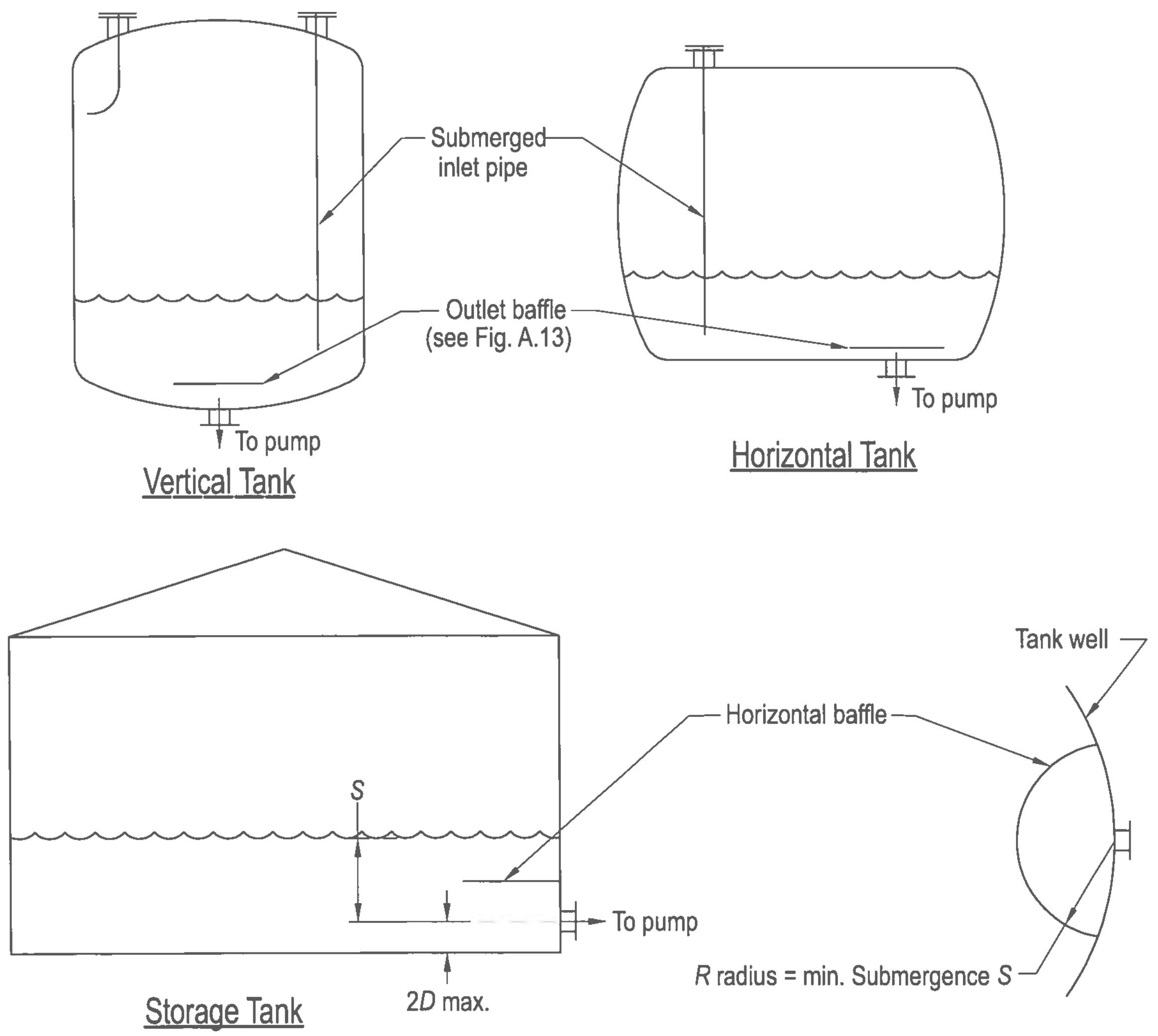


Figure A.14 — Tank inflow and outflow configurations

Appendix B

Sump volume

This appendix is not part of this standard, but is presented to help the user in considering factors beyond the standard sump design.

B.1 Scope

This section on pump sump volumes pertains to constant-speed pumps. For adjustable-speed pumping, sump volume may not need to be considered (assuming adequate pump controls) except for a requirement that the sump volume must be large enough to keep currents sufficiently low.

B.2 General

Pump sumps are required in most pumping systems (1) to distribute inflow to the various pumps and (2) to act as a buffer volume capable of absorbing inflow fluctuations. For constant-speed pumps that operate in an on/off mode, the sump alternately fills and empties at a cyclic rate slow enough to prevent motors and motor starters from overheating. Refer to the pump (not the motor) manufacturer for the allowable cyclic rate.

The active sump volume required for a single constant-speed pump depends on the allowable starts per hour (or the allowable time per cycle). The total time for a cycle is the time to fill plus the time to empty the basin between low (LLL) and high liquid levels (HLL).

$$T = \frac{V}{Q} + \frac{V}{P-Q} = \frac{VP}{Q(P-Q)} \qquad \text{(Eq. B.2-1)}$$

Where:

P = pump discharge capacity, in L/s (ft^3/s), fixed

Q = inflow to sump, in L/s (ft^3/s), variable

T = total cycle time, in s, given

V = active sump volume to be determined

The minimum cycle time occurs when the rate of change of volume (as the basin fills and empties) with respect to inflow is greatest. Rearranging the equation,

$$V = T\left(Q - \frac{Q^2}{P}\right) \qquad \text{(Eq. B.2-2)}$$

Differentiating,

$$\frac{dV}{dQ} = T\left(1 - \frac{2Q}{P}\right) = 0 \qquad \text{(Eq. B.2-3)}$$

From which,

$$Q = \frac{P}{2} \qquad \text{(Eq. B.2-4)}$$

Thus, the inflow rate to be used to determine the sump volume is half the capacity of the pump. Substituting $P/2$ for in the first expression yields:

$$V = T\frac{P}{4} \qquad \text{(Eq. B.2-5)}$$

When two or more pumps are to be operated simultaneously, the equations are still valid if P is taken as the increment of pumpage when another pump is added. Formulas for volume with multiple pump operation including pump alternation and reduced capacity due to friction are complicated, especially if the pumps are of different sizes. Graphical solutions are much simpler, offer insights not possible with formulas, provide a definitive analysis of cycle times and resting times, give start and stop levels, allow the use of pumps with differing capacities, and permit any sort of pump alternation. Several pumps can be alternated to increase cycle time, and the graphical construction clearly shows both cycle times and resting times.

B.3 Construction of a graph

Choose a linear scale of volume for the left *y*-axis. On the right *y*-axis, plot the corresponding liquid levels; that scale is linear for wet wells with vertical sides. For basins with sloping sides (such as trench type), the scale is non-linear as shown in Figure B.1 Plot time on the *x*-axis. With simple pump controllers, separate the start levels for successive pumps by at least 150 mm (6 in) because liquid-level sensing devices need that much differential to operate reliably. Separate the stop levels similarly. Provide a time delay of 5 to 10 seconds on starting to avoid premature operation caused by turbulence.

B.4 Example for a simple controller

Three pumps of equal size are set in a wet well with sloping sides and auxiliary storage, so although the volume scale is linear, the liquid-level scale is not. The discharge rate for a single pump is P_1, so the minimum cycle time occurs when the inflow rate, Q, equals half the outflow rate or $0.5P_1$. Consequently, the slopes of the flow rates to be plotted are $\pm\ 0.5P_1$. When two pumps operate together the total discharge is P_{1+2} (which is less than $2P_1$ because of increased friction losses), and the critical flow rate to be plotted is half the incremental increase of flow when a second pump is brought on line.

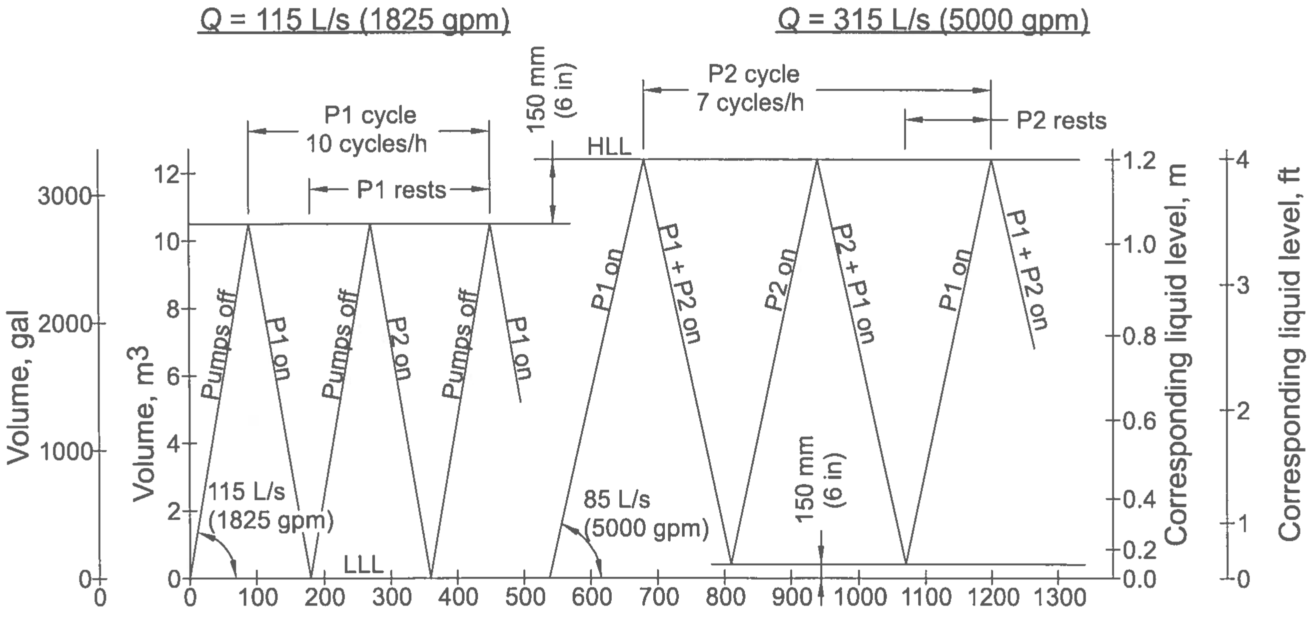


Figure B.1 — Graphical analysis for liquid-level controllers

Assumptions:

Pumps: three, two duty and one standby. Standby pump assumed to be dismantled for repair.

Station Q_{max} = 400 L/s (6350 gpm), so capacity per pump is P_{Qmax} = 200 L/s (3170 gpm).

For single pump operation, $P_1 = P_2$ = 230 L/s (3650 gpm).

Pumps to be alternated.

The pump manufacturer recommends 10 starts per hour or less (360 seconds per start) for the particular equipment considered. Note: consult manufacturer for recommended allowable starts.

Liquid-level fluctuation should not exceed 1.2 m (4 ft).

Solution:

$V = TP/4$ = 360 seconds x 230 (3650)/4 = 20,700 L (5475 gal) = 20.7 m^3 (5475 gal).

But pumps are to alternate, so the volume required is one-half V or 10.35 m^3 (2735 gal).

Critical flow rate = $P_1/2$ = 230 (3650)/2 = 115 L/s (1825 gpm).

See Figure B.1. Start with low liquid level, LLL, and plot slope of critical liquid inflow at +115 L/s (1825 gpm) until volume reaches 10.35 m^3 (2735 gpm).

Pump 1 is now activated, so plot a line downward at a slope of –230 (–3650) + 115 (1825) = –115 L/s (–1825 gpm) as the pump empties the basin. The pump is turned off at LLL. The basin refills at +115 L/s (+1825 gpm).

The pumps are alternated by turning on pump 2 at 10.35 m^3 and stopping it at the LLL. Basin again refills. Each pump cycle is 360 seconds.

When a second (or follow) pump is needed, the total pumpage is 400 m^3/s, but the incremental increase in pumpage is 400 (6350) – 230 (3650) = 170 L/s (2700 gpm).

The critical additional inflow rate is 170 (2700)/2 = 85 L/s (1350 gpm), so the total critical inflow rate is 230 (3650) + 85 (1350) = 315 L/s (5000 gpm).

Start the follow pump, P2, at high liquid level, HLL, which is 10.35 m^3 plus 150 mm (6 in) increase in liquid-level elevation. Both pumps P1 and P2 reduce the volume at 315 (5000) – 400 (6350) = –85 L/s (–1350 gpm).

Pump 1 is turned off at 150 mm (6 in) above LLL, and the basin refills to the HLL at 315 (5000) – 230 (3650) = 85 L/s (1350 gpm) while pump 2 continues to run.

Pump 1 is turned on at HLL. When the liquid surface again reaches LLL + 150 mm (6 in), pump 2 is turned off and rests until the basin is refilled. By alternating pumps, either is restarted in 515 seconds.

More pumps and pumps of different sizes can be analyzed in the same manner.

Other solutions:

Alternators may fail (install a backup) or workers might override the alternator, so designers must decide whether or not to rely on pump alternation.

If pumps are not alternated, the cyclic rate is doubled and so is the size of the pump intake basin.

B.5 Example for programmable controllers

Smart controllers detect whether one or two (or more) pumps are needed, so any pump (whether lead or follow) can use the entire volume of the wet well between LLL and HLL. For a station with three pumps, 150 mm (6 in) of excavation can be saved; with four pumps, the saving is 300 mm (1 ft). The solution, given by Figure B.2, gives a pump cycle of 490 seconds (7.3 cycles/h) during two-pump operation.

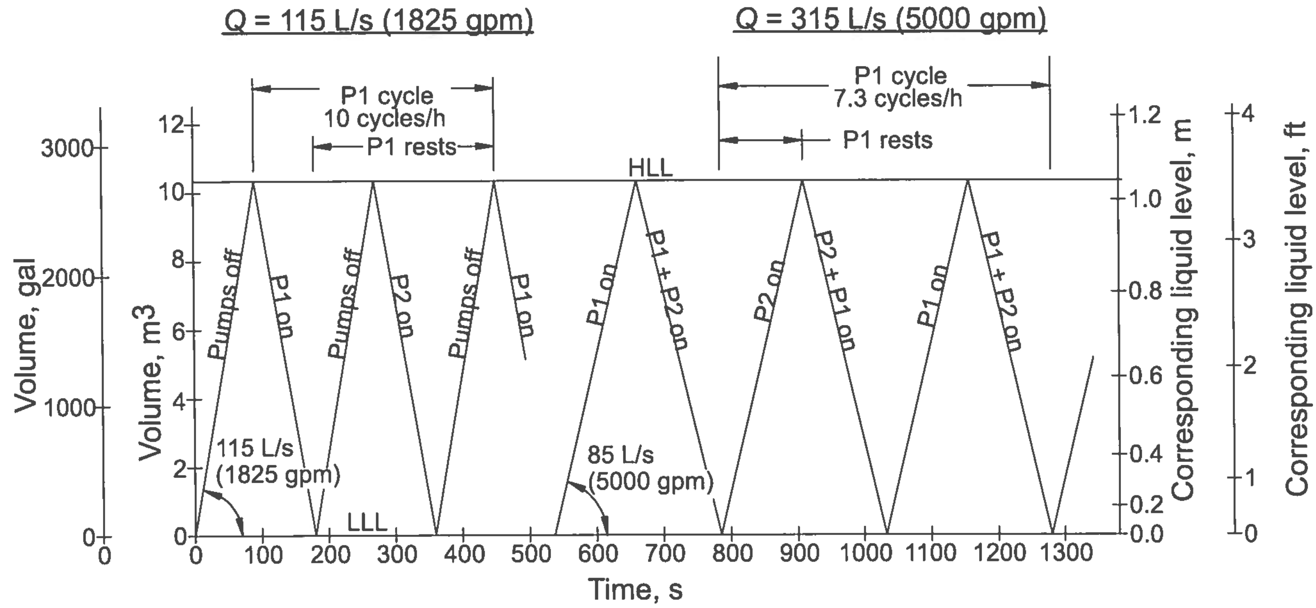


Figure B.2 — Graphical analysis for a "smart" controller

Appendix C

Intake basin entrance conditions, trench-type wet wells for solids-bearing liquids

This appendix is not part of this standard, but is presented to help the user in considering factors beyond the standard sump design.

C.1 Scope

This section pertains to entrance conditions and to volume requirements for trench-type wet wells with variable-speed or constant-speed pumps.

C.2 Entrance conditions

There should be 5 to 10 diameters of straight, uniform, symmetric, and level inlet conduit, and level (or nearly level) inlet pipe leading into the pump intake basin. The pipe should lie in a vertical plane through the pump intakes and well above them as shown in Figures 9.8.2.3.1a through f, 9.8.2.4.1a and b, and 9.8.3.2.2. The intake velocity should be only great enough to keep solids moving, preferably between 0.6 m/s (2.0 ft/s) and 1.2 m/s (4.0 ft/s). In wet wells for intakes consisting of a bend and flare (leading to dry-pit pumps), inlet velocity should not exceed 0.9 m/s (3 ft/s).

C.3 Variable-speed pumps in trench-type wet wells

Little or no storage volume is required for variable-speed pumping because the discharge of the pumps can be easily regulated to match the inflow.

The liquid level in the wet well should be maintained to match the depth in the upstream conduit. Even a slight drop generates bubbles and currents that sweep the bubbles to the intake of the first pump.

C.4 Constant-speed pumps in trench-type wet wells

Some types of wet wells, notably trench, confined, and hopper-bottom circular types, are inherently small and may contain as little as half the active storage volume needed to keep the frequency of motor starts within the manufacturer's recommendations. The active storage volume is obtained by allowing the liquid level to fluctuate, typically about 1.2 m (4.0 ft).

Allowing a free fall or cascade from the inlet into the pool below is poor and improper practice. Even a short drop entrains air bubbles and drives them deep into the pool where they may be drawn into the pumps and thus reduce pump flow rate, head, and efficiency as well as causing damage to the pumps. If the liquid is domestic wastewater, the turbulence sweeps malodorous and corrosive gases into the atmosphere.

C.4.1 Auxiliary storage

Active storage need not be confined to the wet well. Some storage may be allocated to an auxiliary storage vessel. Auxiliary storage should:

- Eliminate any vestige of free fall at all times
- Supply the deficit of the required active storage capacity in an appurtenant structure at low cost
- Discharge liquid horizontally into the wet well pool without turbulence and at low velocities, preferably between 0.6 m/s (2.0 ft/s) and 0.9 m/s (3.0 ft/s)

- Operate automatically with no operator attention
- For wastewater or stormwater, be self-cleaning in every cycle

C.4.2 Approach pipes

One facility that meets the objectives of auxiliary storage is an approach pipe, which is an enlarged pipe laid at a hydraulically steep gradient between the wet well and an upstream manhole. At a gradient of 2% and a length of 60 m (200 ft), the approach pipe would fill and empty with a 1.2-m (4.0-ft) difference between low liquid level (LLL) and high liquid level (HLL). See Figure C.1. Low exit velocities can be obtained by setting the LLL at an appropriate elevation above the invert of the approach pipe so that the turbulence from the hydraulic jump occurs in the pipe and not in the sump.

Beginning with a full approach pipe, the liquid level lowers as a pump is activated and liquid flows over a sloping invert in the upstream manhole to the supercritical velocity given in Table C.1 or C.2. On encountering pooled liquid, as in Figure C.1, the supercritical velocity results in a hydraulic jump with a sequent depth that must not be allowed to reach the soffit of the pipe because entrapped air might result in a violent eruption that could be destructive. In the tables, the sequent depth is limited to 60% of the pipe diameter, and that leaves a free liquid surface 20 pipe diameters long — more than enough for bubbles to rise to the surface and escape up the pipe.

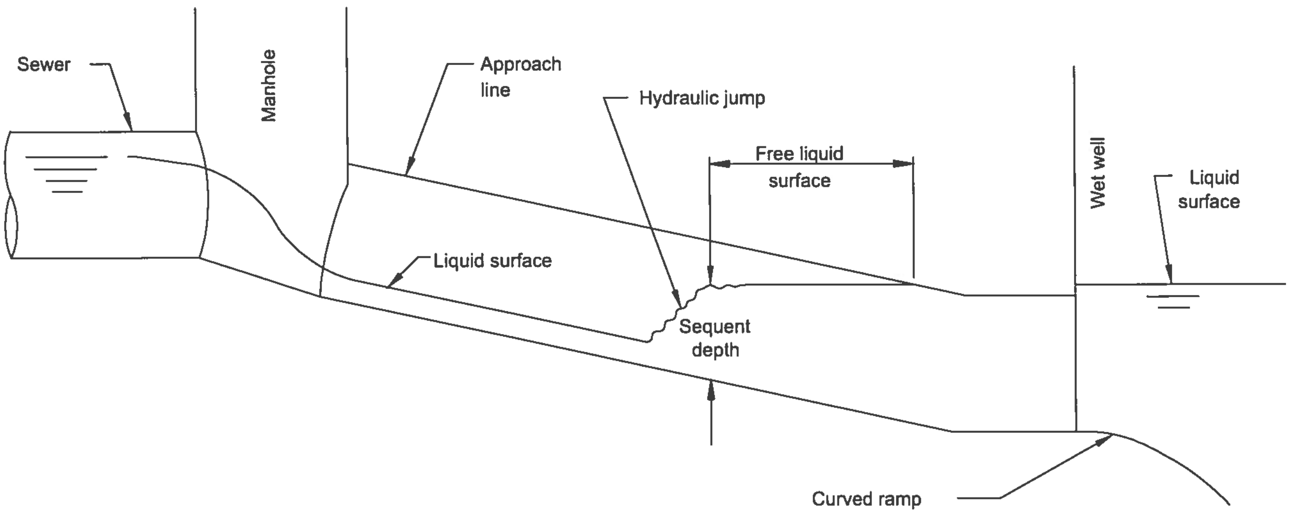


Figure C.1 — Schematic diagram of approach pipe

The Froude number (see Section 9.8.2.5.4) for the jump is less than 2.5, so there is little bubble formation and off-gassing. Note from Tables C.4.2a and b that the useful active storage cross section of the approach pipe varies from 72 to 81% of the total pipe cross-sectional area.

Tables C.1 and C.2 were originally developed by Wheeler (1995) and modified by Cahoon and Sanks (2002). These data for approach pipes at 2% gradient are based on Manning's equation corrected by Escritt (1984) for an *n* of 0.010. Uncorrected, *n* varies as much as 25% with depth. Escritt found that by adding half the width of the liquid surface to the perimeter for calculating the hydraulic radius, *n* was constant within a few percent. A value of 0.0125 for *n* in the uncorrected Manning equation is roughly comparable to an *n* of 0.010 in the equation with the Escritt modification.

These tabular data can be altered for other gradients, *n* values, and sequent depths by using the program, *Approach*, freely available from the Internet at www.coe.montana.edu/ce/joelc/wetwell/.

Table C.1 — Maximum allowable flow rates in approach pipes (metric units)

Slope = 2%, Manning's n = 0.010, Escritt's assumption is used, sequent depth is limited to 60% of pipe diameter.

True Pipe		Q, L/s	Before Jump				After Jump
D_p, mm	Area, m^2		$\frac{y}{D_p}$, %	v, m/s	$\frac{A_e}{A_f}$, %	Froude No.	$\frac{y}{D_p}$, %
254	0.051	20	31	1.4	73	1.91	60
304	0.073	30	31	1.6	74	1.97	60
381	0.114	50	30	1.8	75	2.04	60
457	0.164	80	29	2.0	76	2.10	60
533	0.224	110	28	2.2	77	2.15	60
610	0.292	160	28	2.4	78	2.20	60
686	0.370	210	27	2.6	78	2.24	60
762	0.456	270	27	2.7	79	2.27	60
838	0.552	330	26	2.9	79	2.31	60
914	0.657	410	26	3.0	79	2.34	60
1067	0.894	590	25	3.3	80	2.40	60
1219	1.17	810	25	3.6	80	2.45	60
1372	1.48	1070	24	3.8	81	2.49	60
1524	1.82	1380	24	4.1	81	2.53	60
1676	2.21	1730	24	4.3	82	2.57	60
1829	2.63	2130	24	4.5	82	2.61	60

Escritt's assumption: add half the width of free liquid surface to wetted perimeter in hydraulic radius.
Omitting Escritt's assumption ≈ changing n from 0.010 to 0.0125.
D_p is inside diameter of pipe.
y is depth of flow.
A_e is inside area of pipe above liquid surface.
A_f is inside area of pipe.
For n = 0.009, multiply Q by 92%.
For n = 0.011, multiply Q by 108%.
For n = 0.012, multiply Q by 115%.
For n = 0.013, multiply Q by 122%.

Table C.2 — Maximum allowable flow rates in approach pipes (US customary units)

Slope = 2%, Manning's n = 0.010, Escritt's assumption is used, sequent depth is limited to 60% of pipe diameter.

True Pipe			Before Jump				After Jump
D_p, in.	Area, ft^2	Q, Mgal/d	$\frac{y}{D_p}$, %	v, ft/s	$\frac{A_e}{A_f}$, %	Froude No.	$\frac{y}{D_p}$, %
10	0.545	0.4	31	4.7	73	1.91	60
12	0.748	0.7	31	5.2	74	1.97	60
15	1.23	1.2	30	6.0	75	2.04	60
18	1.77	1.8	29	6.6	76	2.10	60
21	2.41	2.6	28	7.2	77	2.15	60
24	3.14	3.6	28	7.8	78	2.20	60
27	3.98	4.7	27	8.4	78	2.24	60
30	4.91	6.1	27	8.9	79	2.27	60
33	5.94	7.6	26	9.4	79	2.31	60
36	7.07	9.3	26	9.9	79	2.34	60
42	9.62	13.5	25	10.8	80	2.40	60
48	12.6	18.5	25	11.7	80	2.45	60
54	15.9	24.5	24	12.5	81	2.49	60
60	19.6	31.5	24	13.3	81	2.53	60
66	23.8	39.5	24	14.0	82	2.57	60
72	28.3	48.6	24	14.8	82	2.61	60

Escritt's assumption: add half the width of free liquid surface to wetted perimeter in hydraulic radius.
Omitting Escritt's assumption ≈ changing n from 0.010 to 0.0125.
D_p is inside diameter of pipe.
y is depth of flow.
A_e is inside area of pipe above liquid surface.
A_f is inside area of pipe.
For n = 0.009, multiply Q by 92%.
For n = 0.011, multiply Q by 108%.
For n = 0.012, multiply Q by 115%.
For n = 0.013, multiply Q by 122%.

C.4.3 Transition manhole, sewer to approach pipe

The transition in the manhole between the upstream conduit and the approach pipe is designed to accelerate the liquid to the velocities shown in Tables C.1 and C.2. Care must be taken to form a sloping transition between the invert of the upstream conduit or sewer on one side and the invert of the approach pipe on the other side. The drop (and hence the slope) of the transition invert can be found by the application of Bernoulli's equation.

In the sewer, the energy grade line (EGL) lies above the liquid surface by the velocity head, $V^2/2g$. For a sewer flowing full at maximum design flow rate, the EGL is likely to be somewhat above the soffit. In the approach pipe, the EGL is 60% of the D_p above the invert plus the velocity head, and the sum is usually about 75% D_p above the invert.

Locate the approach pipe so that its EGL is below the EGL of the sewer by an amount equal to the expected head loss due to turbulence and friction. As data on head losses are sparse, be conservative and increase the invert drop somewhat to ensure supercritical flow. A small increase in velocity has an even smaller effect on the sequent depth. For example, velocities 20% greater than the values shown in Tables C.1 and C.2 increase the sequent depth from 60 to only 67% D_p. Such an increase reduces safety but, nevertheless, may be tolerable.

C.4.4 Lining

The approach pipe is subject to corrosion caused by sulfuric acid forming above low liquid line by bacteria acting on sulfur compounds. As with the wet well, all surfaces above low liquid level should either be lined with an impervious material (e.g., plastic) immune to corrosion or the pipe itself should be plastic.

C.5 Design examples

Examples of wet well designs for

- Variable-speed pumps
- Constant-speed pumps
- Approach pipes
- Transition manholes

are given by Jones, Sanks, Tchobanoglous, Bosserman, and Jones (2005).

Tables C.1 and C.2 can be modified to other flows, pipeline gradients, or roughnesses by means of the Web site www.coe.montana.edu/ce/joelc/wetwell/.

Appendix D

Performance enhancements for trench-type wet wells

Information in this appendix is not part of this standard, but is presented to help the user in considering factors beyond the standard sump design.

Refer to Section 9.8.1 of the standard, which allows for an intake designed to a geometry other than presented in the standard and such as contained in these appendices, to be deemed to comply with the standard, if the intake is tested by prototype testing or a physical model study performed in accordance with Section 9.8.4, and the test results comply with the acceptance criteria in Section 9.8.4.6.

Requirements for physical hydraulic model study are given in Section 9.8.4.

D.1 Scope

This appendix describes improvements (devices or solutions) that reduce swirling and vortices. Nonuniform velocities in the throats of pump intakes have not been a problem observed in trench-type wet wells, and that subject is not addressed.

D.2 Performance of bare trenches

D.2.1 Normal operation

During normal operation, the incoming liquid jet travels to the end wall with moderate abatement, dives to the floor, returns upstream along the floor to the ramp, and moves upward to join with the incoming jet, thus setting up a circulation pattern. The floor current is confined by the trench but nevertheless wanders somewhat so that it may be relatively strong at one side and weak at the other side. The differential current at the suction bell creates swirling that, in middle pump intakes, exceeds the standard of acceptance in Section 9.8.4.7. Swirling changes the angle of attack on the impeller blades, which results in loss of head, capacity, and efficiency, or may substantially increase motor loads.

Flow separation creates strong floor vortices under the suction bell and moderately strong subsurface sidewall vortices opposite the suction bell and somewhat below the rim of the bell. The vortices become smaller but more intense within the suction throat and may cause cavitation, excessive noise, vibration, and maintenance.

Surface vortices can occasionally form when intake submergence is low, so the submergence should be above that required by Equation 9.8.2.1-2 at all normal flow rates. During pump-down, vortices become strong enough to suck scum, bubbles, or even a solid core of air into the pump. See Figure 9.8.4.5a.

D.2.2 Cleaning operations for wastewater and stormwater wet wells

Cleaning is accomplished by either of the procedures detailed in Section 9.8.3.1.6. Whatever the procedure, the flow down the ramp attains very high velocity, and a hydraulic jump proceeds down the trench to the last pump as shown in Figure D.1. The hydraulic jump suspends all solids, which are then swept into the last pump. Friction rapidly reduces the high velocity and the Froude number. It is important that the Froude number be at least 3 at the last pump and that the last suction bell be submerged at least $D/2$ below the sequent depth as shown in Figure 9.8.3.2.2, because a large, air-core vortex usually forms beside the suction bell to prevent lowering the liquid surface much below Froude number 3.0. The Froude number is defined by Equation 9.8.4.3-1 wherein L is the depth of flow.)

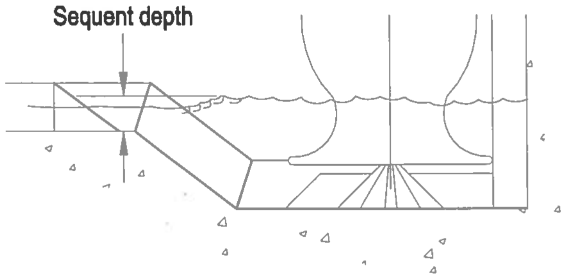


Figure D.1 — Open trench-type wet well hydraulic jump

D.3 Enhancing normal operation

D.3.1 Inlet baffles

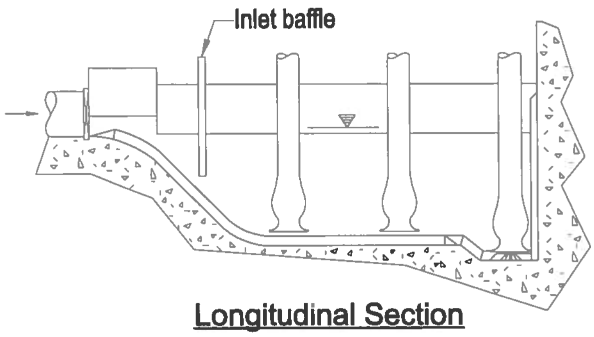


Figure D.2 — Open trench–type wet well with inlet baffle

An inlet or target baffle as in Figure D.2 is advantageous in changing the inlet liquid jet to a gentle downstream flow above the trench, reducing the upstream current along the floor, and reducing swirling in pump intakes. Both horizontal and vertical baffles are reasonably effective, but the latter is less critical in size and placement and less prone to catching stringy material. The inlet baffle in Figure D.2 cut the average swirl in half in one physical model study with no other enhancements, although the results were still somewhat short of meeting the requirements of Section 9.8.4.7. The baffle was 1.67D wide and submerged to 1.0D below the ramp apex. The location of the target baffle can be scaled from the figure with adequate accuracy. Inlet baffles seem to improve pump performance, but the extent of improvement and the optimum dimensions and location can be determined only by a physical model study.

D.3.2 Suction bell vanes

Four (or more) suction bell vanes as shown in Figure D.3 can effectively control swirling if they are large enough. There must always be a passage sufficient to pass a 75-mm (3-in) sphere for small pumping stations and larger spheres for large stations. Cast-iron suction bells with vanes are unlikely to be available, but for the few needed in a pumping station, it may be cost-effective for any shop with programmable plasma cutters to fabricate bells of 316L or 347 stainless steel with welded vanes.

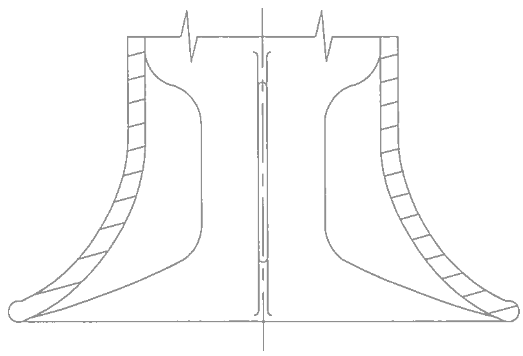


Figure D.3 — Suction bell vanes

D.3.3 Floor cones

For clear liquids, floor cones, as shown in Figure D.4, can minimize floor vortices. When equipped with vanes, they can also reduce swirling. They are excellent and relatively inexpensive for all pumps in clear liquid pumping stations. For very nonuniform approach flow to the wet well, four vanes are not enough to produce acceptable swirling, but six or eight vanes can be very effective.

For solids-bearing liquids, floor cones cannot be used under upstream pumps because the high-velocity flow during cleaning would be completely disrupted. However, a cone under the last pump is desirable. Two vanes, as shown in Figure D.5, are all that is necessary. Make the clearance between the suction bell and the vanes at least 75 mm (3 in). The rear vane can extend to the anti-rotation baffle. If there is a flow splitter under the upstream pumps, then the splitter should be terminated after the next to last pump bell.

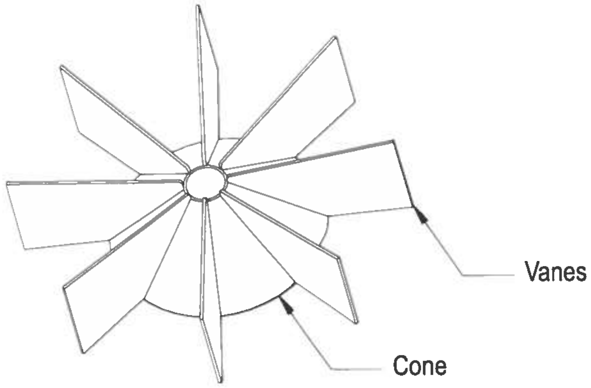


Figure D.4 — Floor cone with vanes for clear liquids

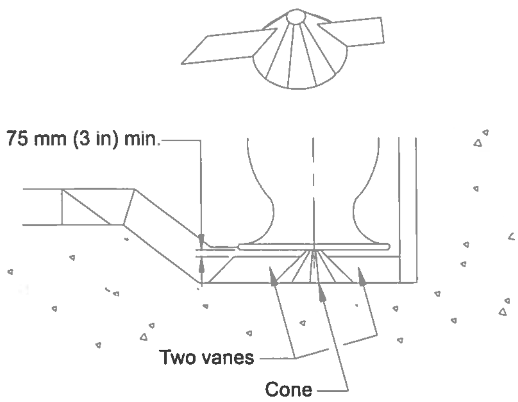


Figure D.5 — Floor cone with vanes for solids-bearing liquids

D.3.4 Flow splitters in wastewater wet wells

Flow splitters can be made of stainless steel plate 6 to 10 mm (1/4 to 3/8 in) thick. They can be anchored by welding them to stainless-steel embedments (Figure D.6) set at suitable intervals. Flow splitters can also be set in a shallow depression and anchored with straps welded to the bottom of the flow splitter. The straps are fastened in the trench with anchor bolts set in epoxy (or other two-component systems) in drilled holes. Bolt heads and nuts are then covered with grout. Embedments are preferred.

In some wet wells, the flow splitters have been terminated at the foot of the ramp. However, regardless of the geometry of the terminating nose, the high-velocity liquid striking the nose bursts into spray and loses much of its energy, so it is far better to extend the flow splitter to the top of the ramp where the liquid velocity is much lower and there is sufficient length down the ramp for recovery of small disturbances.

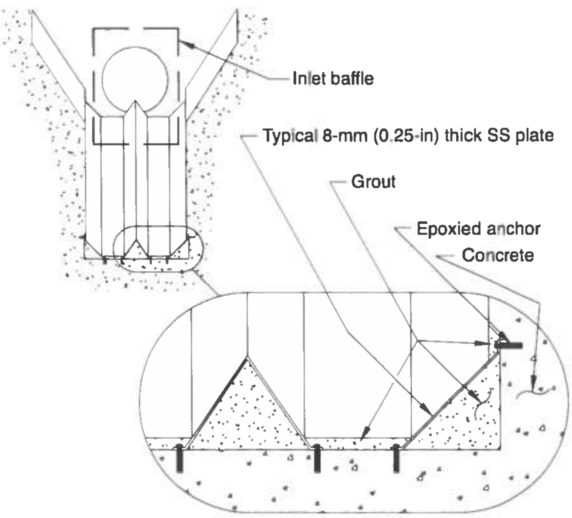


Figure D.6 — Flow splitter in wet well

On ramp curves with radius, *r*, the radius of curvature, *R*, of the plate is

$$R = \frac{r}{\sin \alpha} \quad \text{(Eq. D.3.4-1)}$$

where α is the angle between the concrete floor and the plate. At the top of the ramp, the nose can be made short and blunt if the velocity is not much above critical (critical velocity corresponds to a Froude number of 1.0). If the velocity significantly exceeds critical, the nose should be gradually tapered to zero at the top of the ramp. As ramps and floors are not likely to be accurately formed, it is wise to make a light wood model of the splitter, place it on the concrete, and scribe offset lines to the concrete surface so that any irregularity can be precisely met.

A tapered nose can be made by cutting the plate at its intersection with the ramp on a radius of

$$R = \frac{r}{\sin\alpha\cos\beta} \qquad \text{(Eq. D.3.4-2)}$$

where β is the angle between the ramp centerline and the intersection of plate and ramp. The outside radius can vary from $(r + h)/\sin\alpha$ to $r/\sin\alpha$ or even less depending on the wanted refinements in the nose shape (where h is the height of the splitter). The height of the nose varies from zero at the top of the ramp to h where it joins the rest of the flow splitter. That junction requires the insertion of a small triangular filler plate. These refinements can be developed in the wooden model.

D.3.5 Fillets

Fillets with a 45 degree (preferred) to 55 degree slope are effective in eliminating sidewall vortices. The top of the fillets must be no lower than $D/8$ below the suction bell. Fillets can be made larger if desired to reduce channel width, increase flow depth, and decrease friction loss during pump-down for cleaning.

Fillets are best made of shotcrete (Gunite) sprayed, screeded, and troweled smooth. They should be reinforced and anchored into the corner. As with flow splitters, fillets should be extended to the top of the ramp to produce a good flow pattern down the ramp.

D.3.6 Maintaining cleaning velocity

The high velocity produced by the ramp quickly dissipates due to friction. See Appendix L for informative material regarding calculations for trench-type wet wells. It quickly solves the velocities and the hydraulic and energy profiles down the ramp and along the trench, calculates the Froude numbers, and plots sequent depths at intervals. (This program cannot be used if a flow splitter is terminated at the foot of the ramp because of the unknown loss of energy when liquid strikes the splitter nose and bursts into spray.)

Velocity along the floor can be maximized by (1) specifying concrete to be smoothly troweled, (2) by lining the bottom of the trench with plastic or other smooth coatings, (3) by confining the flow with large fillets and a flow splitter with maximum (45 degree) side slopes, and, as a last resort, (4) by sloping the bottom of the trench beginning at the point where the velocity is as low as can be tolerated.

D.3.7 Last pump

The one device universally required during cleaning is the anti-rotation baffle between the end pump and the backwall shown in Figures 9.8.3.2.2 and D.5. Without it, liquid circulates between the pump and the wall so that the current on one side of the pump actually goes upstream and keeps the hydraulic jump far upstream. It may be necessary to weld a part of the baffle to the pump suction nozzle to limit sufficiently the size of any opening. The vanes attached to the cone are not only desirable, they may be necessary to prevent the circulation of liquid beneath the suction bell.

During pump-down, the pump is subjected to severe service due to excessively low submergence and cavitation. Select robust pumps. Clean the wet well at the smallest practical flow rate so as to dewater the basin and complete cleaning as quickly as possible.

D.3.8 Ramps

Concrete for ramps can be cast in stair steps with dowels placed to anchor a reinforced blanket of shotcrete. Screed the shotcrete to templates temporarily bolted to the sides of the trench and trowel the surface smooth.

D.3.9 Choice of enhancements

Judgement as to which enhancements to use should be based primarily on their effectiveness in improving performance. Note that their cost as a percentage of the cost of the pumping station is insignificant whereas the effect on performance and reducing maintenance may be very significant. Life-cycle costs are likely to favor these enhancements and the improved performance.

D.3.10 Omission of enhancements

In wet wells for station capacities less than about 0.44 m^3/s (10 mgd), it may be more cost-effective to omit enhancements such as flow splitters and fillets in favor of using impeller materials that are cavitation-resistant. See ANSI/HI 9.1-9.5 *Pumps - General Guidelines for Types, Definitions, Application, Sound Measurement and Decontamination*. Although flow splitters and fillets can be placed in trenches that are only 0.9 m (3.0 ft) wide, their cost is at a premium because of the crowded work space. The premium is less in trenches 1.1 m (3.5 ft) wide and disappears for trenches 1.2 m (4 ft) wide.

Without suction bell vanes, the average swirl in a middle pump operating alone may exceed 5 degrees (the allowable limit) about half the time. If another pump is also running, the swirl may be excessive most of the time. Vanes are always desirable, and a target baffle may be added for certainty.

Appendix E

Aspects of design of rectangular wet wells for solids-bearing liquids

Information in this appendix is not part of this standard, but is presented to help the user in considering factors beyond the standard sump design.

Refer to Section 9.8.1 of the standard, which allows for an intake designed to a geometry other than presented in the standard and such as contained in these appendices, to be deemed to comply with the standard, if the intake is tested by prototype testing or a physical model study performed in accordance with Section 9.8.4, and the test results comply with the acceptance criteria in Section 9.8.4.6.

Requirements for physical hydraulic model study are given in Section 9.8.4.

E.1 Introduction

The material presented in this appendix is provided for the convenience of the intake design engineer who faces the challenge of optimizing sump geometry for new or existing rectangular wet wells with solids-bearing liquids. Many retrofit installations require the upgrade/replacement of mechanical equipment and an increased station capacity, yet intake hydraulics are many times neglected. This can cause a variety of problems ranging from a noisy installation to adverse hydraulic conditions at the pump inlet, which can reduce equipment life.

Further, this material transmits general experience and knowledge gained over many years of improving the hydraulics of intake structures, and such educational material may not include the specific recommendations appropriate for a standard. Features described herein have been effective in the past, but may or may not be able to be incorporated in an existing wet well or for a given set of site-specific conditions. Other remedial features not provided herein may also be effective, and a physical model study is needed to verify whether or not a given remedial design feature results in acceptable flow conditions. This is particularly true because adding a remedial feature to solve one flow problem may have detrimental effects on other flow phenomena of concern.

Rectangular wet wells pose special challenges as described in Section 9.8.3.4, but are quite often used because of the physical size requirements of installations with multiple pumps, ease of construction, and reuse of existing structures. In such cases, incorporating special provisions to ensure proper inflow to the pumps and to minimize dead zones where solids can settle and accumulate is essential for optimal station performance.

Two important design requirements are: preventing significant quantities of air from reaching the impeller, and disposal of settled and floating solids. The recommendations in this appendix can be used as they are, or with appropriate variations to meet the requirements of most installations.

E.2 Design capacity

A sump designed in accordance with the recommendations in this appendix is smaller than a conventional sump. Consequently, there may be less buffer volume to accommodate transient variations of the flow rate. Also there is no extra retention volume to store the inflow in excess of the total pump capacity (the pipe volumes are usually much larger than any pump station volume). All critical aspects of operation should be considered in a proper design.

E.3 Design alternatives – general

A well-designed baffle wall minimizes air entrainment due to falling liquid. The flow from the inlet pipe strikes the partition wall then flows down into the inlet chamber through the slot in the floor of the baffle. The slot distributes the flow evenly toward all the pump inlets. The partition wall is high enough to ensure that the flow does not surge over it. Although the flow in the inlet chamber is highly turbulent, various materials can collect there. In such cases, side overflow weirs or side gaps may be used to carry away debris and thus prevent its accumulation. (The top of the partition wall, or parts of it, should be below the highest start level of any of the pumps to allow transport of the floating material into the pump chamber). Equipping the sump with fillets, baffles, and/or benching is often beneficial depending on the number of pumps and their size. To avoid preswirl in the pump chamber, the inlet pipe must have a straight length of five pipe diameters upstream from the sump.

E.4 Front – high-level entry intake structure

The central front high-level entry is the sump design shown in Figure E.1. In this configuration, the flow does not have to make a horizontal turn, which might induce mass rotation in the sump. The exact sump design varies with the number of pumps and pump size.

E.5 Side – high-level entry intake structure

If the piping system and the sump location do not allow for a front entry inlet, then a side entry inlet with a baffle wall modified with ports can be used. This configuration is shown in Figure E.3. In this design, the baffle wall redirects the incoming flow and distributes the flow evenly toward the pumps through the ports.

E.6 Side – low-level entry intake structure

In this arrangement, shown in Figure E.6 with a straight baffle wall, either the sump or the sewer is below the normal liquid level in the sump, or an open channel supplies the sump. In the absence of falling flow in the entrance, no intense entrainment of air takes place. Consequently, the inlet chamber can be greatly simplified because its only task is to distribute the flow evenly to the pumps.

E.7 Cleaning procedures

Removal of solids from wet wells, designed in accordance with these principles, can be adequate to prevent the continued buildup of solids by operating the pumps selectively to lower the level in the wet well until just before the pumps lose prime. Both settled and floating solids are largely removed by the pumping equipment and discharged into the force main (or discharge conduit). Scum is removed by the surface vortices that form beside a pump when submersion of the intake is greatly reduced.

Vortices are small and removal of floating solids can be substantially improved by supplemental features, such as induced turbulence or liquid sprays that quickly move surface scum to the active pump. This cleaning procedure momentarily subjects the pumps to vibration, dry running, and other severe conditions. Consult the manufacturer when selecting the pumping equipment. The frequency of the cleaning cycle depends on local conditions, and therefore should be determined by experience at the site.

As with all wastewater wet wells, grease accumulates on the walls and must occasionally be removed. It is easily washed off surfaces lined with plastic by means of a hose or liquid lance using about 1.5 L/s (25 gpm) of liquid at a nozzle Pitot pressure of 600 kPa (90 lb/in^2). Concrete surfaces are more difficult to cleanse.

E.8 Sump dimensions

Refer to Figure E.7 for recommended sump dimensions. Note: Submersible pumps are shown in the figures but the designs and dimensions also apply to applications using dry-pit pumps.

Note: Minimum required wet-well levels are as given in Figures 9.8.3.3.1a and b.

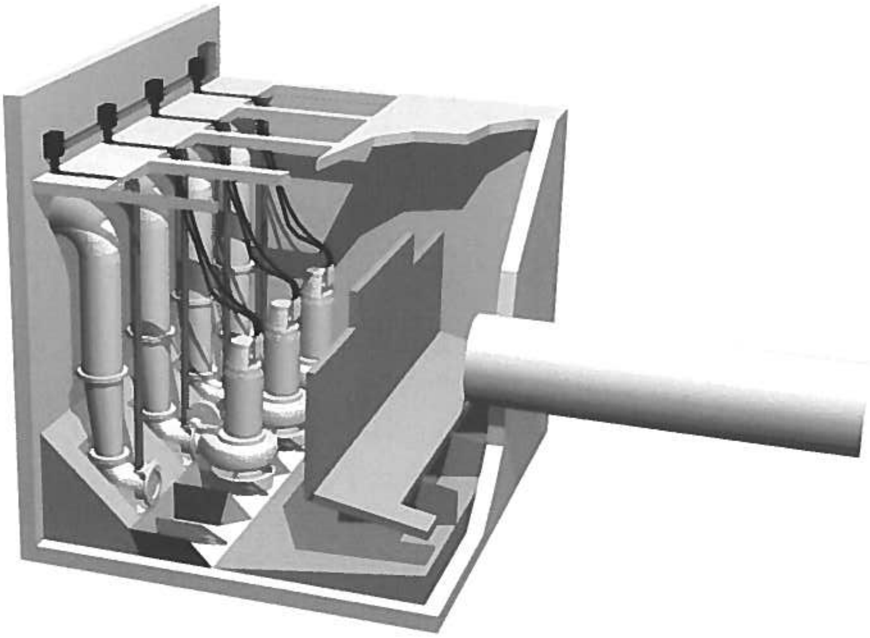


Figure E.1 — Front – high-level entry

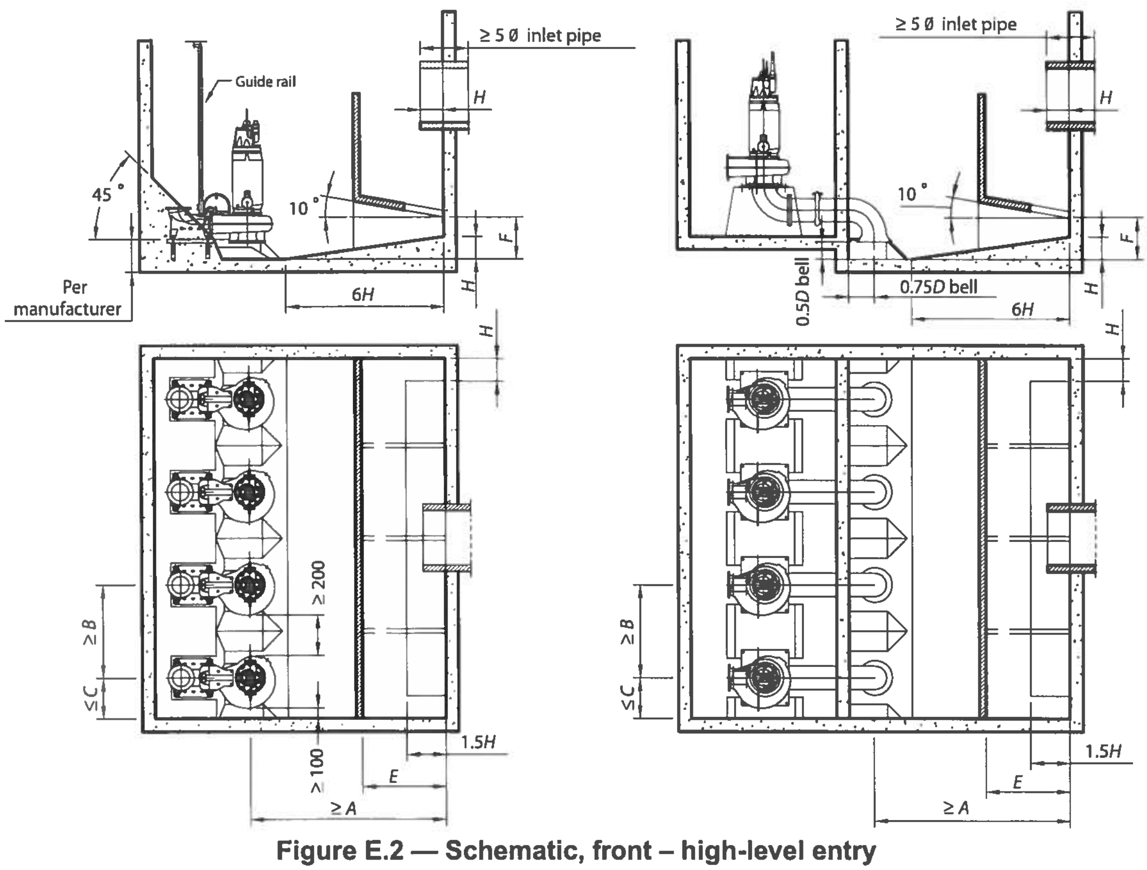


Figure E.2 — Schematic, front – high-level entry

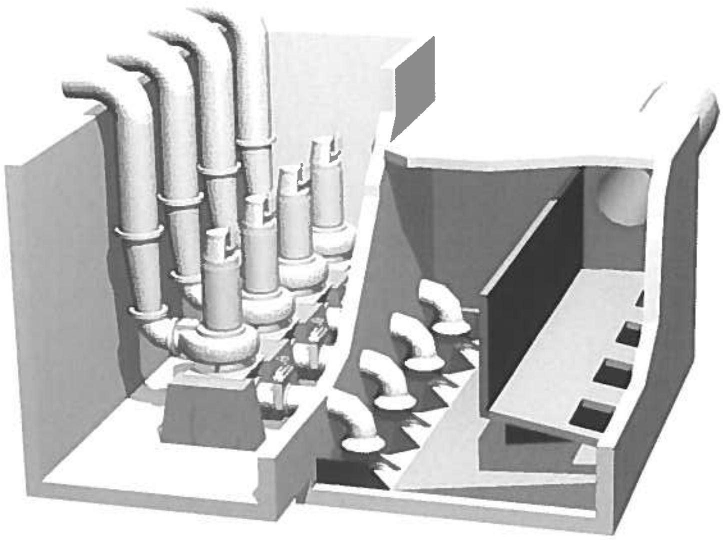


Figure E.3 — Side – high-level entry

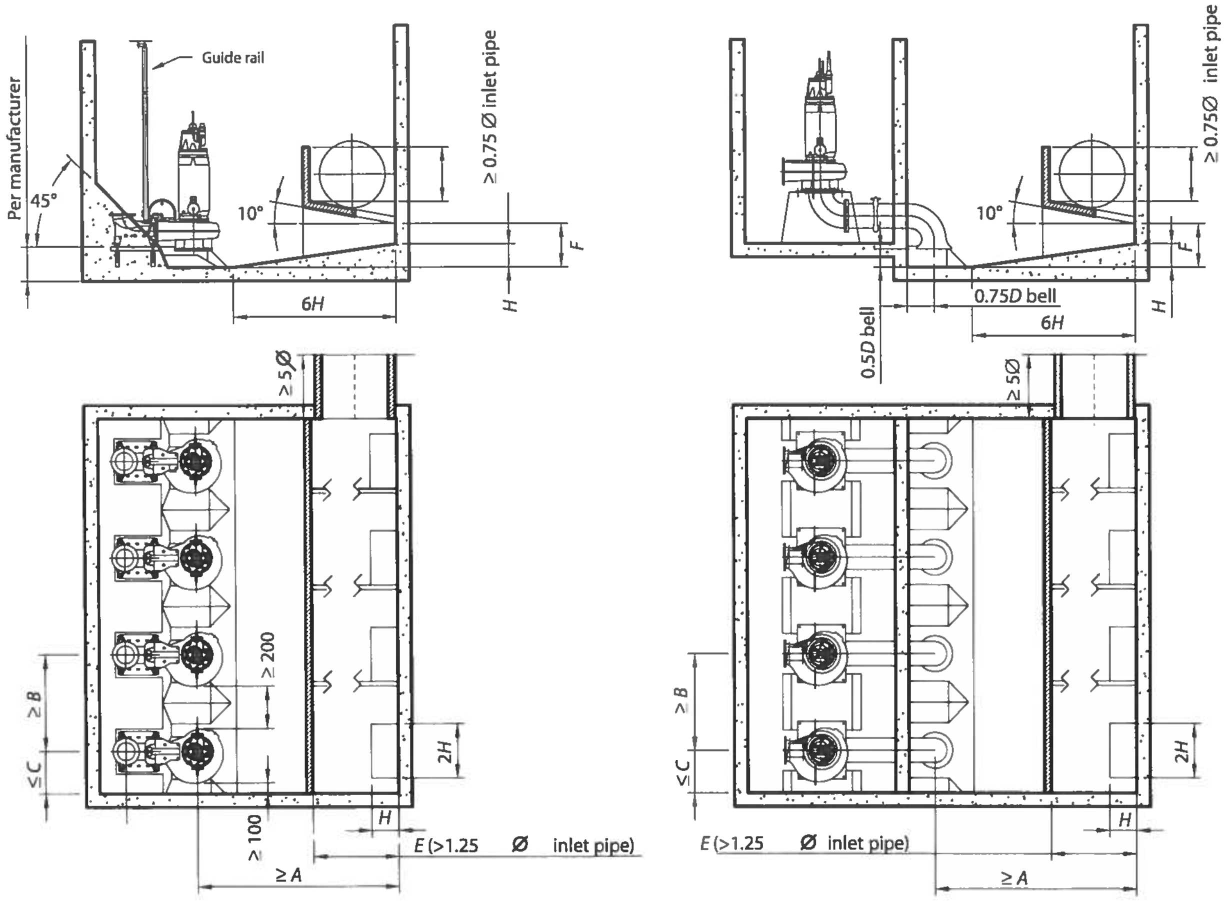


Figure E.4 — Schematic, side – high-level entry

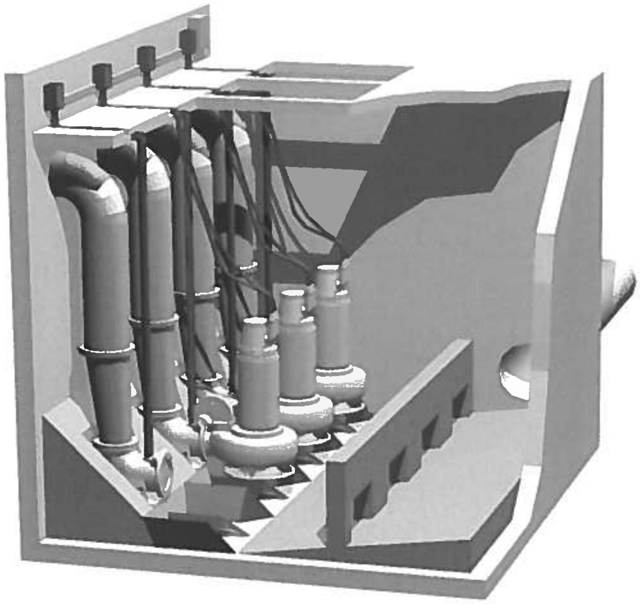


Figure E.5 — Side – low-level entry

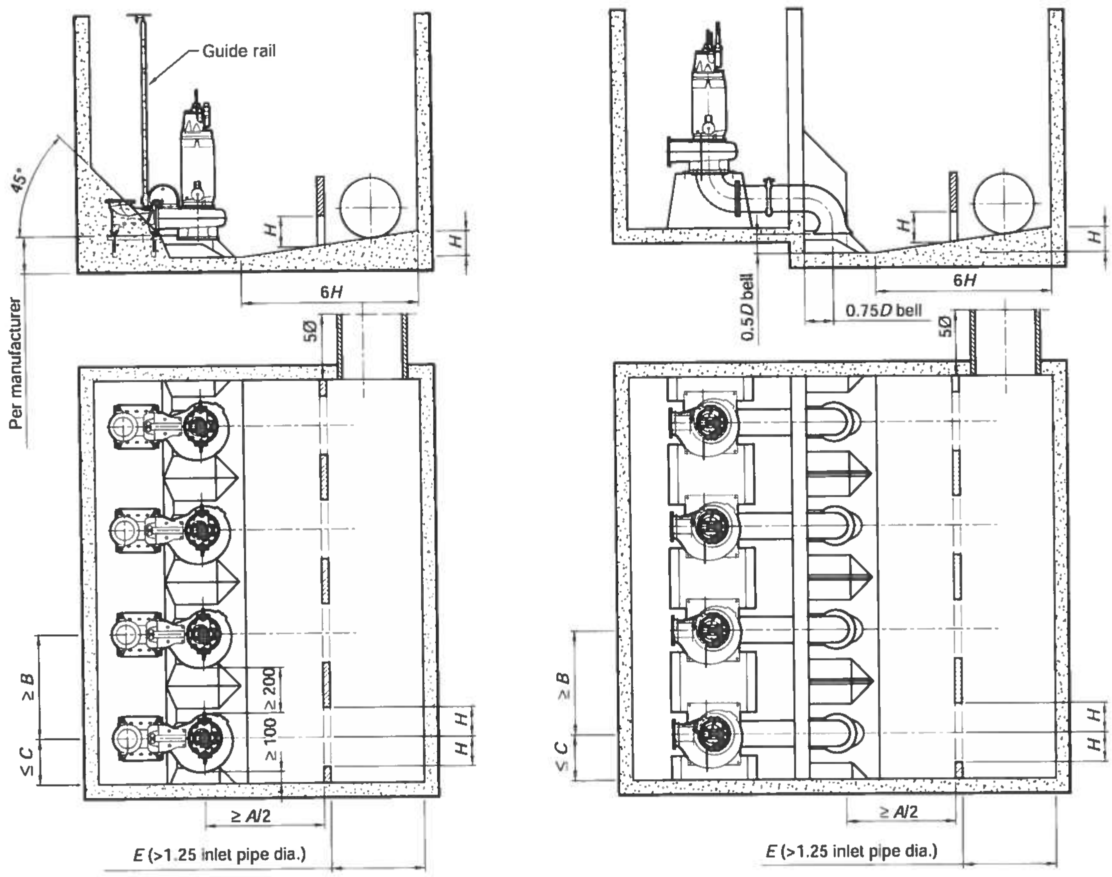


Figure E.6 — Schematic, side – low-level entry

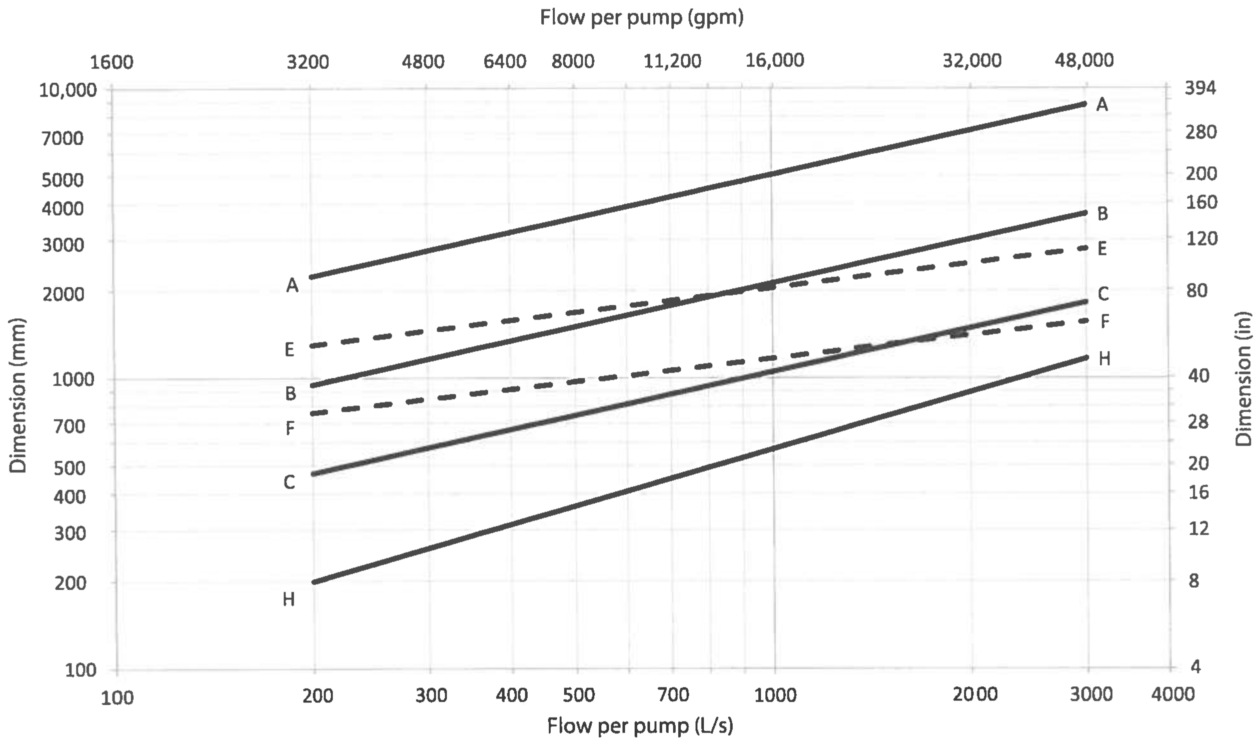


Figure E.7 — Recommended sump dimensions

Appendix F

Suction bell design

The design information in this appendix is provided for general information and is not intended to modify or supercede standard or proprietary designs provided by pump manufacturers.

F.1 Introduction

The function of a flared suction bell intake is to direct the flow of liquid into an intake pipe or into the throat of the first-stage suction impeller of a pump. It is a flared converging bell-shaped section designed to guide the liquid uniformly into the intake pipe or pump impeller with a minimum of hydraulic losses. Refer to Figure F.1.

F.2 Bell outside diameter

The flared-bell outside diameter *D* can be determined per Section 9.8.5 based on a recommended average inlet velocity of 5.5 ft/s, Table 9.8.5.2b.

F.3 Ratio of bell outside diameter to throat diameter

The bell diameter *D* typically falls within 1.7 to 2.3 times the impeller eye throat diameter *d* or, in axial flow pumps, the propeller outside diameter, or intake pipe throat diameter. Smaller or greater ratios of *D*/*d* are possible, especially when it is a flared intake for a conduit upstream of the pump suction impeller.

Bell diameter ratios less than 1.7 are possible when the approach flow is sufficiently symmetrical about the axis of the suction impeller.

F.4 Suction bell length

Suction bell length (*L*) is selected based on hydraulic, mechanical, and economic considerations. A bell with a shaft tail bearing has to accommodate the required bearing hub. A cone attached to the floor or suspended from the pump eliminates a submerged vortex directly under the bell. The hydraulic loss of a well-formed suction bell is typically within a range of 0.04 to 0.09 times the velocity head corresponding to the throat diameter.

F.5 Bell intake shape

The bell intake shape is designed to ensure that the flow velocity change is gradual throughout the intake cross section. The contour is typically designed by one of the following curves that form an arc of a curve:

a) Circle

b) Ellipse

c) Parabola

d) Compound based on two radii

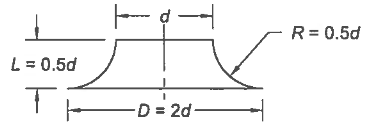
e) Lemniscates of Bernoulli

f) Compound curves based on the above, or other methods

After the dimensions *D* and *d* are established, the dimension *L* can be calculated or selected per the specific curve shape geometry dimensions.

A pump bell designed with a bearing hub and support vanes (ribs) may have a flow area blockage caused by these elements if appropriate design adjustments are not made. The bell shape may need to be adjusted to compensate for blockage elements and ensure a smooth rate of velocity change and minimize energy losses.

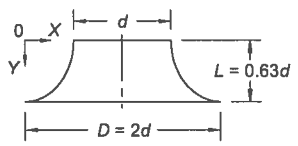
i. Circle



D and d selected as required, selected $D = 2d$.

$$L = R = \frac{D - d}{2}$$

ii. Ellipse

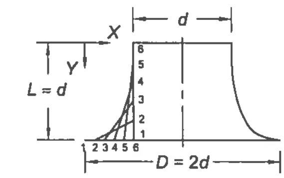


D, d and L selected as required; selected $D = 2d$ and $L = 0.63d$.
The ellipse is defined by the equation in rectangular coordinates.

$$Y = \frac{L}{D - d}\sqrt{(D - d)^2 - 4x^2}$$

Y-coordinates are calculated by entering increasing values of x-coordinates starting from 0.
When $L = \frac{D - d}{2}$ the curve is a circle like in option i.

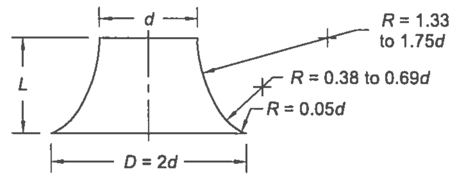
iii. Parabola



D, d and L selected as required; selected $D = 2d$ and $L = d$.

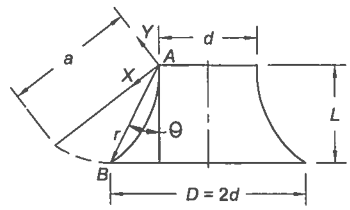
The parabola shape is created graphically by dividing the $\frac{D - d}{2}$ distance on x-axis and L distance on y-axis in equal spaces. Connecting the points with same numbers defines the parabola contour.

iv. Compound



D, d and L selected as required; selected $D = 2d$ and $L = 0.97d$.

V. Lemniscates of Bernoulli



D, d and L selected as required; selected $D = 2d$, $L = d$.

The lemniscates of Bernoulli is defined by the equation in polar coordinates.

$$R = a\sqrt{\cos 2\theta}$$

At first, a is selected approx. 5% longer than AB.

$$AB = \sqrt{\left(\frac{D - d}{2}\right)^2 + L}$$

R values are calculated by increasing values of angle θ.

After the first try, a different value of a may need to be selected in order to have the curve coincide with points A and B.

Figure F.1 — Bell intake shapes

Appendix G

Submersible pumps – well motor type

This appendix is not part of this standard, but is presented to help the user in considering factors beyond the standard sump design.

G.1 Submersible pumps – well motor type

Design criteria are provided for both wet-pit type and closed bottom can below-grade suction intakes (Figure G.1). Proper placement of this type of submersible pump in a well is beyond the scope of this standard.

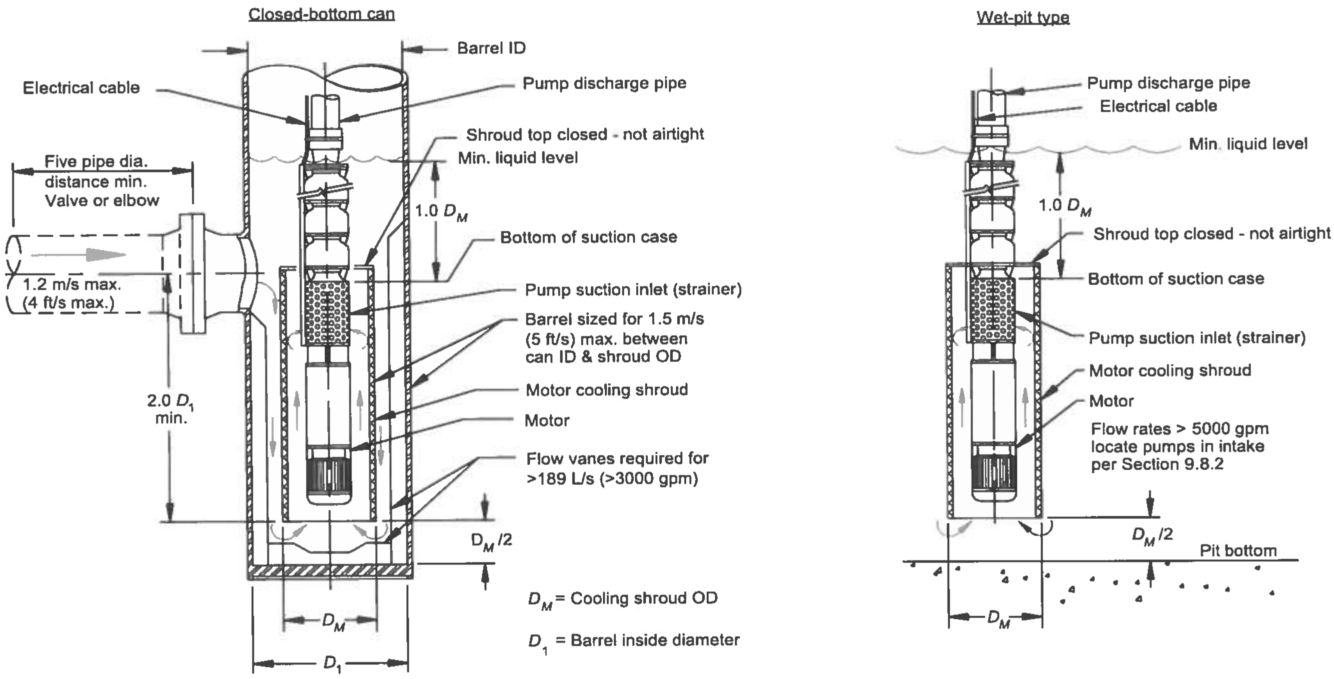


Figure G.1 — Submersible vertical turbine pump

A submersible well-type motor normally requires a minimum flow of liquid around the immersed motor to provide for adequate motor cooling. For many applications a shroud is required to ensure proper cooling flow around the motor. Sizing of the cooling shroud for internal flow velocities must be referred to the pump manufacturer. The top of the shroud must include a cover to restrict downward flow of liquid to the pump inlet, while allowing for venting of air from the shroud.

The intake piping must be large enough to limit drawdown below the recommended minimum liquid level to a period of less than three seconds during start-up.

The first-stage impeller is located above both the strainer and motor. A suction case is located below the first-stage impeller. The confined flow pathway provided by the motor cooling shroud is very desirable in developing a uniform flow to the first-stage impeller. Therefore, placement of the wet-pit-type submersible per Section 9.8.2.1 is only necessary for flow rates above 315 L/s (5000 gpm).

Appendix H

Modification of existing pumping systems

This appendix is not part of this standard, but is presented to help the user in considering factors involved in the modification of existing pumping systems.

H.1 Scope

This appendix applies to the modification of existing pumping systems. Typical modifications involve system rehabilitation, system upgrades, and system expansions.

H.2 Purpose

The purpose of this appendix is to raise awareness within the scope of the intake design standard for the need to reconfirm the design of any pumping system when any component of the original design has (or will be) changed.

H.3 Recommendations

Design of even the most basic pump system involves consideration of the site, hydraulic performance, civil and mechanical design, transient analysis, types of equipment, construction issues, power considerations, and control logic/instrumentation; all in the light of current standards and accepted practices.

To obtain satisfactory results it is necessary that these aspects all be reconfirmed when any characteristic of the original design is modified. Failure to do so risks serious operational problems in pumping systems. These problems usually prove difficult and very costly to resolve.

A common modification to an existing pumping system is to increase the rate of flow through the system, which may be inadequate to accommodate the additional flow satisfactorily.

In such cases the modified design should be reconfirmed as if it were a new design. A physical model study is particularly useful in avoiding problems. Refer to Section 9.8.4.

Appendix I

Alternate formed suction intake designs

Information in this appendix is not part of this standard, but is presented to help the user in considering factors beyond the standard sump design.

Refer to Section 9.8.4 of the standard, which allows for an intake designed to a geometry other than presented in the standard and such as contained in these appendices, to be deemed to comply with the standard, if the intake is tested by prototype testing or a physical model study performed in accordance with Section 9.8.4, and the test results comply with the acceptance criteria in Section 9.8.4.6.

Requirements for physical hydraulic model study are given in Section 9.8.4.

I.1 Stork-type formed suction intake

The principal converging element of a stork-type formed suction intake is shown in Figures I.1a, b, and c. The dimensions are given as ratios of the suction bell throat (Ø1.0*D*). This design originated from Dutch polder pumps. The simple geometry of this design is appropriate for concrete construction. The opening width (4.25*D* as shown) may vary between 3.25 and 5.40*D*. The inlet geometry is adapted to this design by filleted or tapered walls extended to meet the approach channel or intake bay. Though relatively insensitive to upstream conditions, entrance cross-flow velocities exceeding 3.5 m/s (12 ft/s) will adversely affect intake performance and are to be avoided. The flow splitter located below the suction bell is tapered to a final width of 0.04*D* to minimize the wake. Depending on FSI size, it may be most practical to form the upper portion of the splitter using steel plate.

I.2 Shoe-box-type formed suction intake

The fundamental design elements of a shoe-box formed suction intake are shown in Figure I.2. The primary advantages to this configuration are the ability to use the inlet as a remedial device in existing pump sumps and that it does not require removal of the pump or pump bell. The dimensions are given as ratios of the bell diameter *D*. The overall width of the intake is equal to 2*D* and the height at the bell is set at 0.5*D*, allowing it to be used in a typical existing intake. The design has been developed during a series of physical model studies and details of the development were presented in a comprehensive paper by Werth and Cheek (2004).

The inlet geometry consists of flat sides with the exception of a simple curved backwall. Fillets and splitters are included within the inlet to prevent submerged vortex activity and flow-straightening vanes are included at the entrance for use in applications with cross-flow. A flared entrance is used to reduce the intake velocity and reduce submergence requirements. Tests show the inlet to be highly effective with cross-flow velocities of up to 0.75 m/s (2.5 ft/s) and minimum submergence requirements as presented in this standard. Higher cross-flow velocities and lower submergence levels may be acceptable but should be verified with a physical model study. The intake can be easily fabricated out of steel and can be installed without removal of an existing pump or bell.

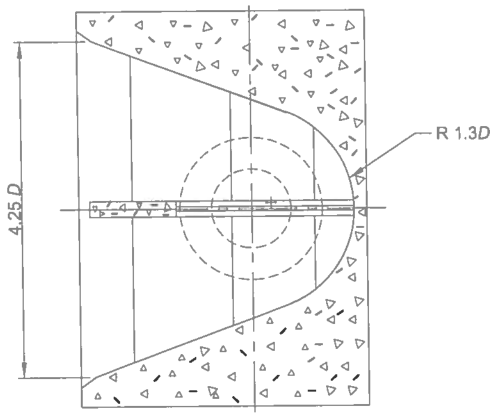


Figure I.1a — Stork-type FSI, plan view

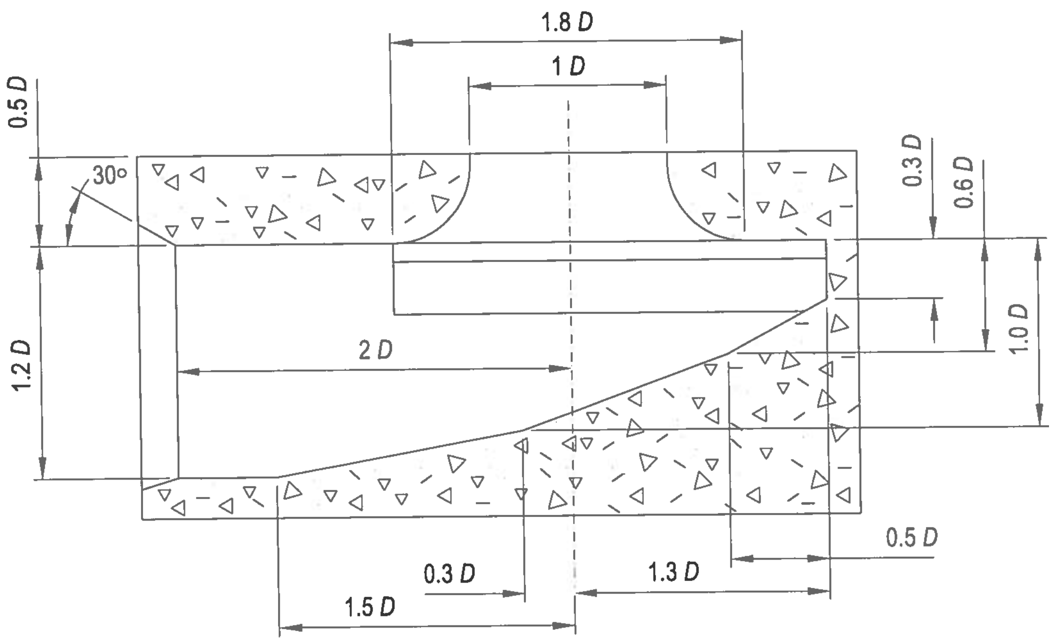


Figure I.1b — Stork-type FSI, elevation view

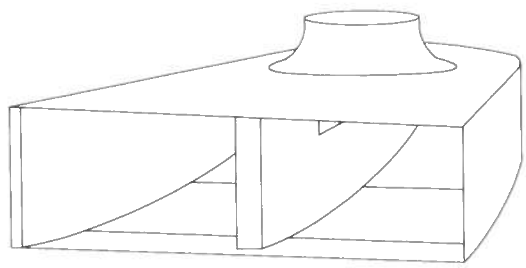


Figure I.1c — Stork-type FSI, perspective view

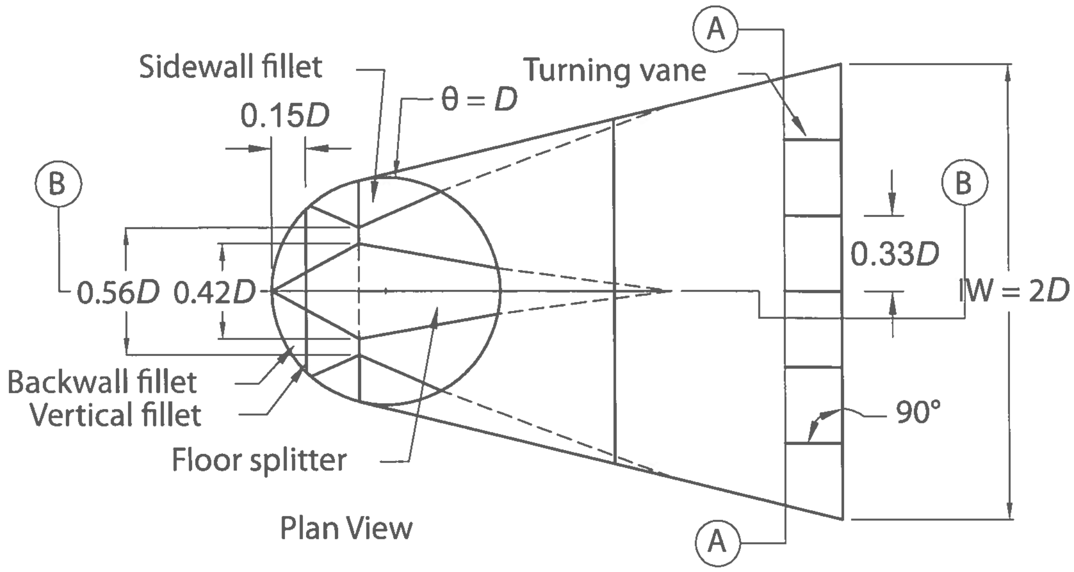


Figure I.2 — Shoe-box-type FSI, plan view

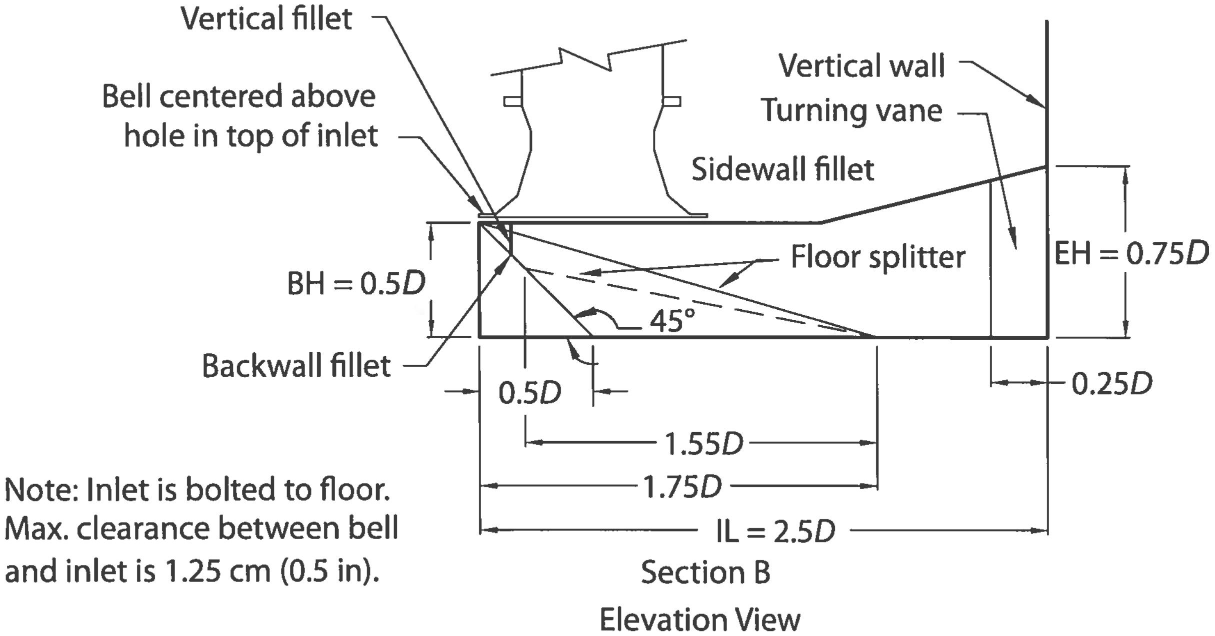


Figure I.3 — Shoe-box-type FSI, Section B

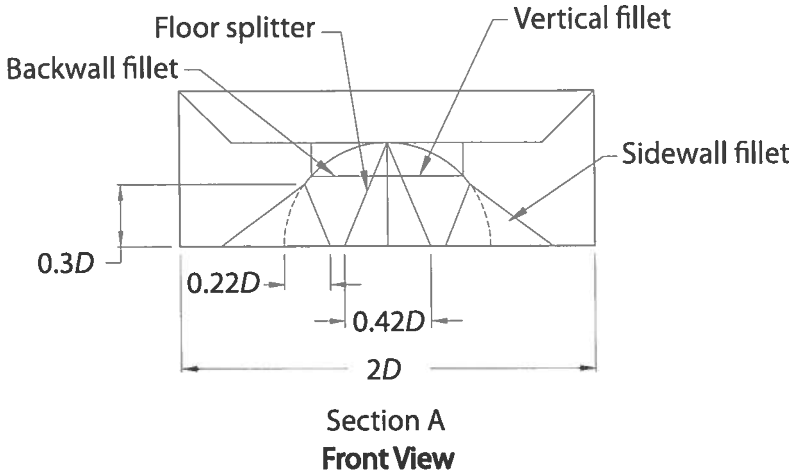


Figure I.4 — Shoe-box-type FSI, Section A

Appendix J

Rectangular intakes for shallow liquid source

Information in this appendix is not part of this standard, but is presented to help the user in considering factors beyond the standard sump design.

Refer to Section 9.8.4 of the standard, which allows for an intake designed to a geometry other than presented in the standard and such as contained in these appendices, to be deemed to comply with the standard, if the intake is tested by prototype testing or a physical model study performed in accordance with Section 9.8.4, and the test results comply with the acceptance criteria in Section 9.8.4.6.

Requirements for physical hydraulic model study are given in Section 9.8.4.

J.1 General

When the liquid source is shallow relative to the required pump submergence, such as is frequently found with cooling tower basins, the alternative configuration described in this appendix may be used in place of the rectangular geometry recommended in Section 9.8.2.1. This alternative configuration is recommended when:

a) The minimum depth of liquid in the source basin is less than one half of the minimum required depth of liquid in the sump.[1]

b) The source basin floor is generally level within the vicinity of the sump.

c) The source basin walls adjacent to the sump are vertical.

d) The sump is oriented so that its longitudinal axis is perpendicular to the adjacent source basin walls.

e) The sump contains no more than three pumps.

The intent of this appendix is to provide recommendations for anticipating and preventing the occurrence of inlet control[2] at the entrance to the sump, and to provide a geometric alternative to the long structure that would result from applying the 10-degree maximum floor slope recommended in Section 9.8.2.1.

J.2 Entrance conditions

When the liquid depth of the source is shallower than required to satisfy the pump, NPSHR, or to control surface vortices, a vertical transition is necessary at the entrance to the sump to effect the depth increase. Although it is not strictly necessary to adhere to the maximum allowable floor slope, α, of 10 degrees (Figure 9.8.2.1.4a) for the intake described in this section, particular attention must be given to the entrance condition to provide flow that is stable and well-distributed.

To ensure that flow does not pass through critical depth at the entrance to the sump and is reasonably stable, the Froude number upstream from the entrance to the sump must not exceed 0.3. To satisfy this Froude number requirement, the depth of liquid upstream from the entrance to the sump must be considered with the sump width and flow, so that:

---

[1] In this case, the minimum depth of liquid in the sump is the greater of the depth required to satisfy pump NPSHR, or the depth to minimize surface vortices as determined by Equation 9.8.6-1.

[2] *Inlet control* is a term used to describe the restriction on gravity-driven flow at an abrupt transition or entrance to a channel or culvert, which is imposed when the flow approaches critical depth and velocity.

$$H_1 \geq C\left(\frac{Q}{W_1}\right)^{0.667} \qquad \text{(Eq. J.2-1)}$$

Where:

Q = total flow at W_1, in L/s (ft^3/s)

H_1 = liquid depth at the entrance to the intake structure, in m (ft) (See Figure J.1)

W_1 = width at the entrance to the intake structure, in m (ft)

C = 0.01 if flow is in L/s and lengths are in m

C = 0.7 if flow is in ft^3/s and lengths are in ft

Increasing the liquid depth immediately upstream from the sump entrance is the most effective means of reducing the Froude number. The increased depth may be achieved by raising the minimum liquid surface elevation in the source liquid basin, reducing the floor elevation in the source liquid basin, or by incorporating an intermediate step into the source basin floor design immediately upstream from the entrance to the sump. The plan dimensions of the intermediate step must be such that L_1 and L_2 have the minimum dimensions shown in Figure J.1, and the length of boundary between the basin floor and the intermediate step must be such that the Froude number along the entire length also does not exceed 0.3. That is, calculate the minimum depth above the source basin floor by substituting H_2 for H_1 and the boundary length of the intermediate step for W in Equation J.2-1. In this case, Q in Equation J.2-1 is the total station flow.

Designers should note that, depending on actual operating conditions, the maximum Froude number at the entrance to a pump bay may occur when a single pump operates at its runout flow and the liquid surface elevation in the basin is at its minimum.

J.3 Vertical transition

The transition between the floor of the source liquid basin (or intermediate step) and the floor of the pump sump may be either sloped or abrupt. Sloped floors may improve the stability of flow through the structure, but typically do so by increasing overall length and facility cost. If a sloping transition is used, the distance from the toe of the slope to the pumps should be held to the recommendation for Z_2 in Figure 9.8.2.1.4a and Table 9.8.2.1.4a.

J.4 Pump bay dividing walls and details near the entrance

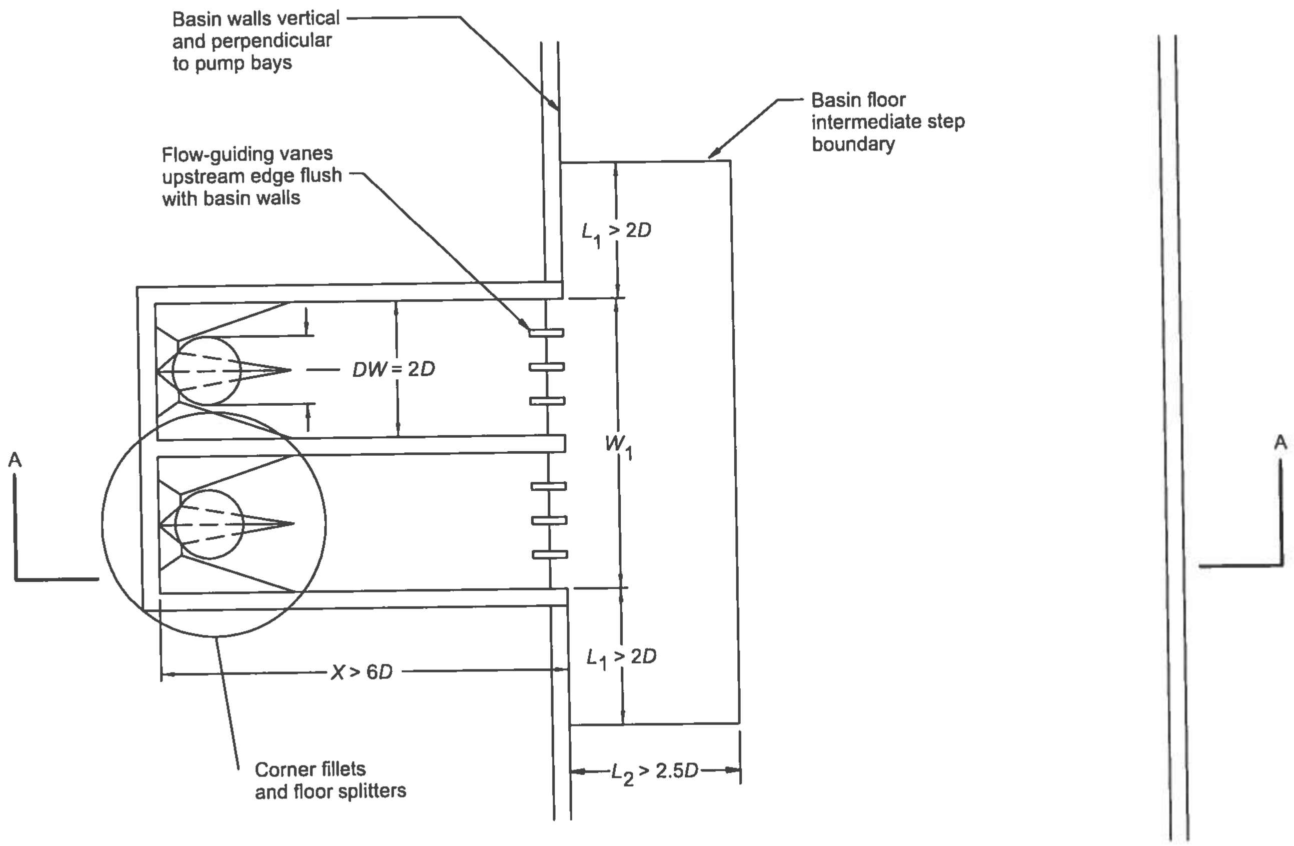
Each pump must be separated from the others with a dividing wall. Each dividing wall must begin at the entrance flush with the inside surface of the source liquid basin walls and extend completely to the sump's backwall. Smaller pumps such as screen wash liquid, service liquid, or auxiliary pumps may be placed upstream from the curtain wall provided their combined capacity does not exceed 15% of the main pump flow.

Flow-guiding vanes must be used at the entrance to the intake structure to prevent flow from contracting or becoming poorly distributed. These vanes must be arranged so that they are flush with both the inside face of the source liquid basin wall and the upstream end of the pump bay dividing walls. Their length (the minimum length shall be $W/20$) must be at least equal to the clear distance between them, and their number and thickness such that they obstruct less than 15% of the open area if the actual minimum depth is near to that dictated by Equation J.2-1. If construction or other concerns dictate that it is necessary to obstruct a greater portion of the pump bay entrance width with these vanes, the minimum depth, H_1, must be increased by decreasing W in Equation J.2-1 accordingly.

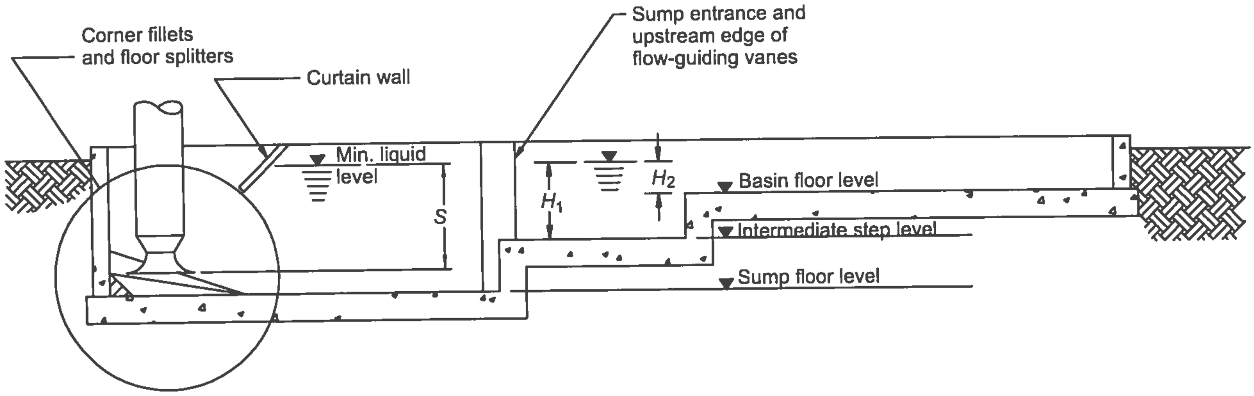
J.5 Pump bay details near the pumps

Geometric details near the pumps must include corner fillets at the junctions between the side- and backwalls and floor. Center splitters must be centered beneath the pumps to prevent the formation of floor vortices and swirl. Refer to Figure J.2.

A curtain wall is placed upstream from the pumps to assist in directing surface currents towards the pumps and to reduce potential for the formation of surface vortices.

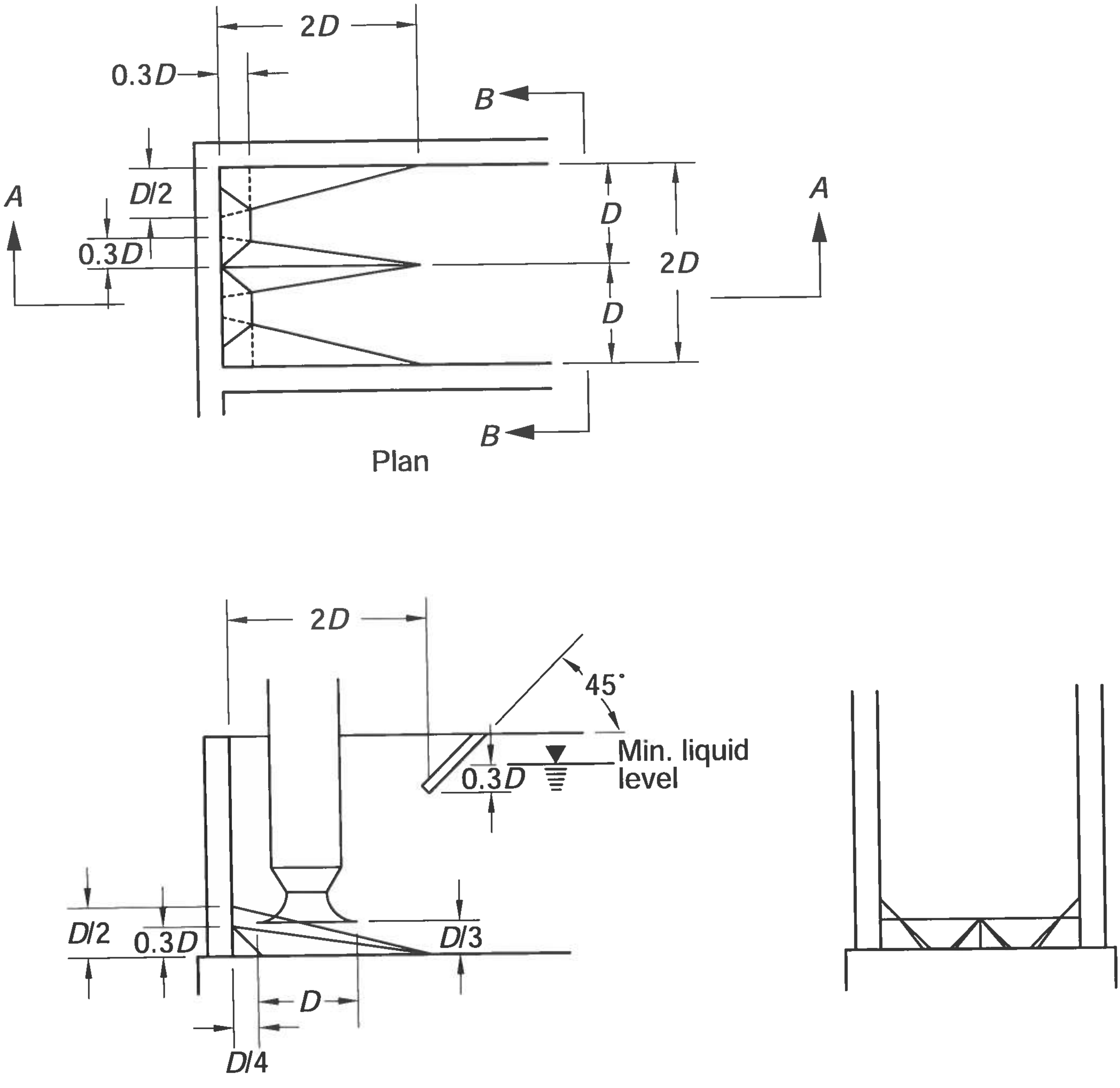


Plan



Section A-A

Figure J.1 — Configuration for rectangular intakes withdrawing from shallow liquid source, maximum three pumps (refer to Figure J.2)



Section A-A

Section B-B

Figure J.2 — Pump bay details near the pump bells for rectangular intakes with a shallow liquid source

Appendix K

Influence of pump selection on intake design

This appendix is not part of this standard, but is presented to help the user in considering the influence of pump selection on intake design.

K.1 Influence of pump selection on intake design

The pump selection and the system curve characteristics have an influence on the intake design, as will be illustrated in this appendix. The selection of a pump "design point" may not represent the normal operating point and hence, not the best flow to use for the intake design for each pump. An example is when multiple pumps operate in parallel and there is a significant friction loss increase in the total system.

Figure K.1 represents three pumps in parallel to achieve the design flow of a sewer lift station. Because the station must meet this maximum wet weather flow, the designer often selects that flow and head per pump as the "design point." This may be fine for acceptance of the pump but may not be the proper design flow for the intake design. In the case of a sewer lift station, for most of the time, only one or two pumps may be needed.

As can be seen from Figure K.1, the flow per pump increases as the number of pumps operated decreases. With two pumps on, the flow per pump increases by nearly 27% compared to three pumps on. With one pump, the flow would be 55% higher if the pump could operate successfully at that runout condition. Thus, if the design point is used for setting the intake design, the intake design may be inadequate and result in unfavorable inlet conditions.

For this example, the operation of just one pump probably results in flow well beyond the acceptable or allowable operating range of the pump. Additionally, the intake based on the original design point will exacerbate the unacceptable operation of one pump.

Figure K.1 includes another significant assumption and that is that the system curve is a fixed quantity. In practice this is rarely, if ever, true. Instead, the friction factor of the system is usually not known with precision and even if it is, friction will usually change over time as the pipe ages or accumulates corrosion or other deposit layers on the pipe. On top of this, the static head of a system can also vary when either the intake wet well level changes or the level changes at the end of the pipe. This case of varying friction as well as varying static head is illustrated in Figure K.2.

As can be seen in Figure K.2, the potential variation in flow per pump becomes even greater than the simplified system curve case of Figure K.1. Now the potential flow per pump is even greater and this influences the performance of the intake to the pump.

One approach that designers often take is to include variable-speed drives to attempt to lower the flow per pump and keep the pump within its allowable operating range when operating on one or two pumps.

Figure K.3 illustrates the application of a variable-speed drive to one pump operating. Each line on Figure K.3 represents a 10% reduction in speed from the 100% speed. For the design point to fall within the system curve range, the speed has to be reduced to about 60% of speed. On clear fluids this may be an acceptable turndown but, for sewage, there could be a problem with the velocity through the pump being low enough that the pump becomes plugged with debris.

The pump selection engineer may want to consider selecting two different-sized pumps to cover the range of flow encountered so that performance is optimized for normal operations and can still meet the required maximum flow design.

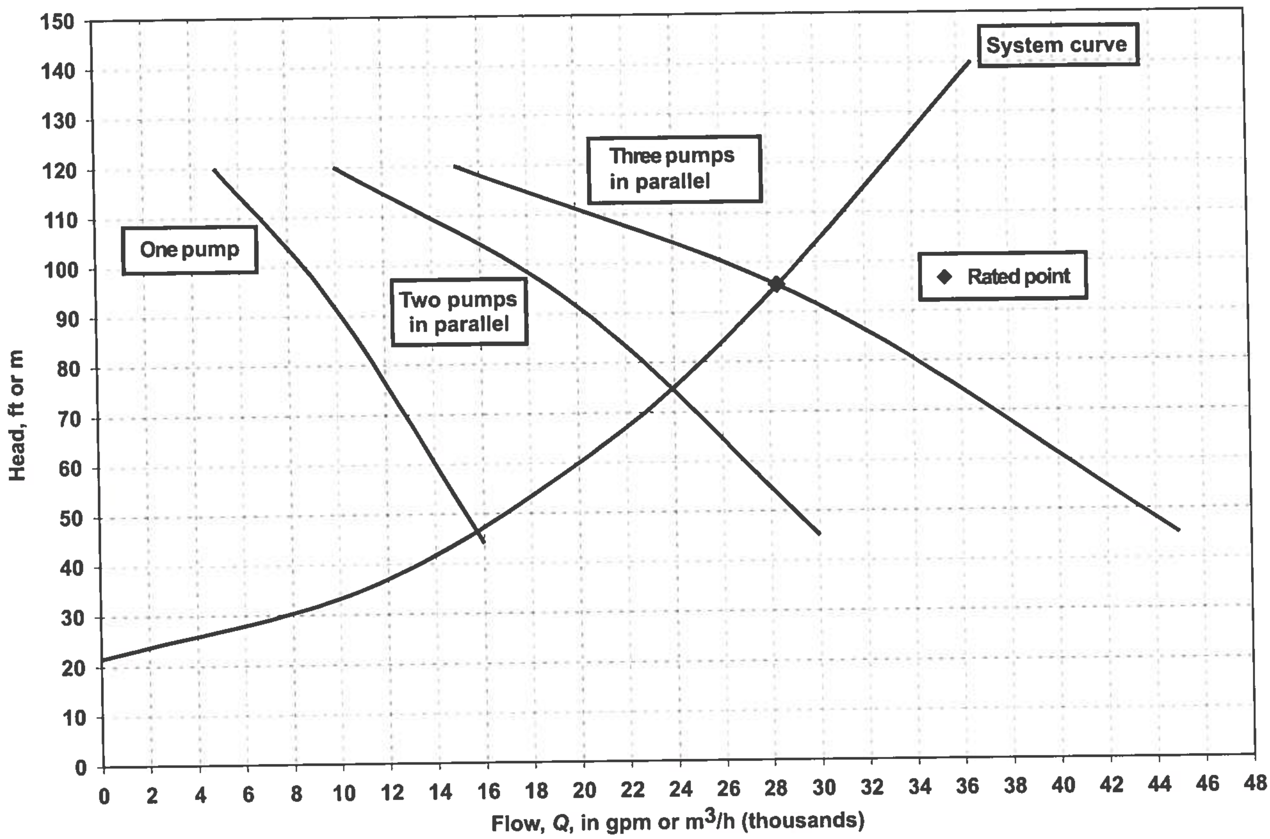


Figure K.1 — Simplified system curve

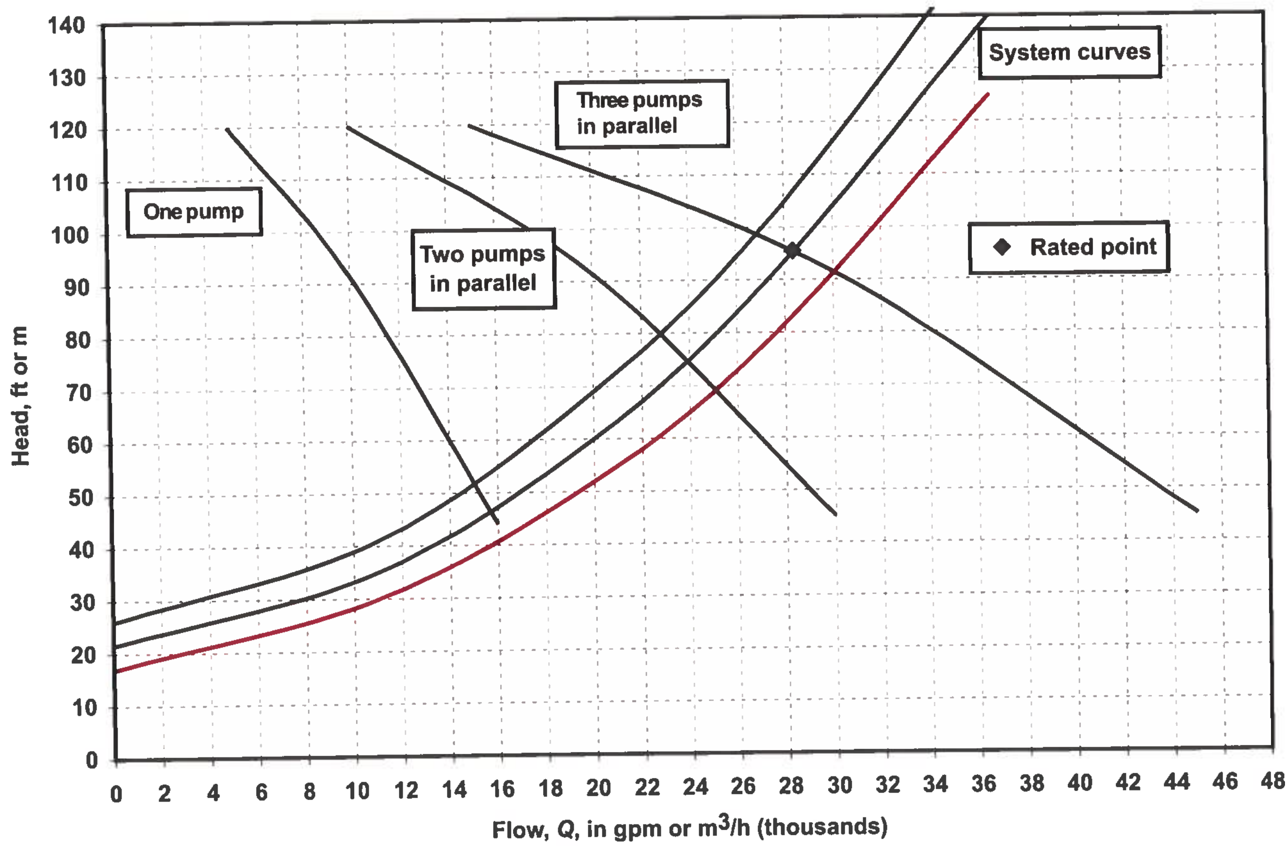


Figure K.2 — Multiple system curves

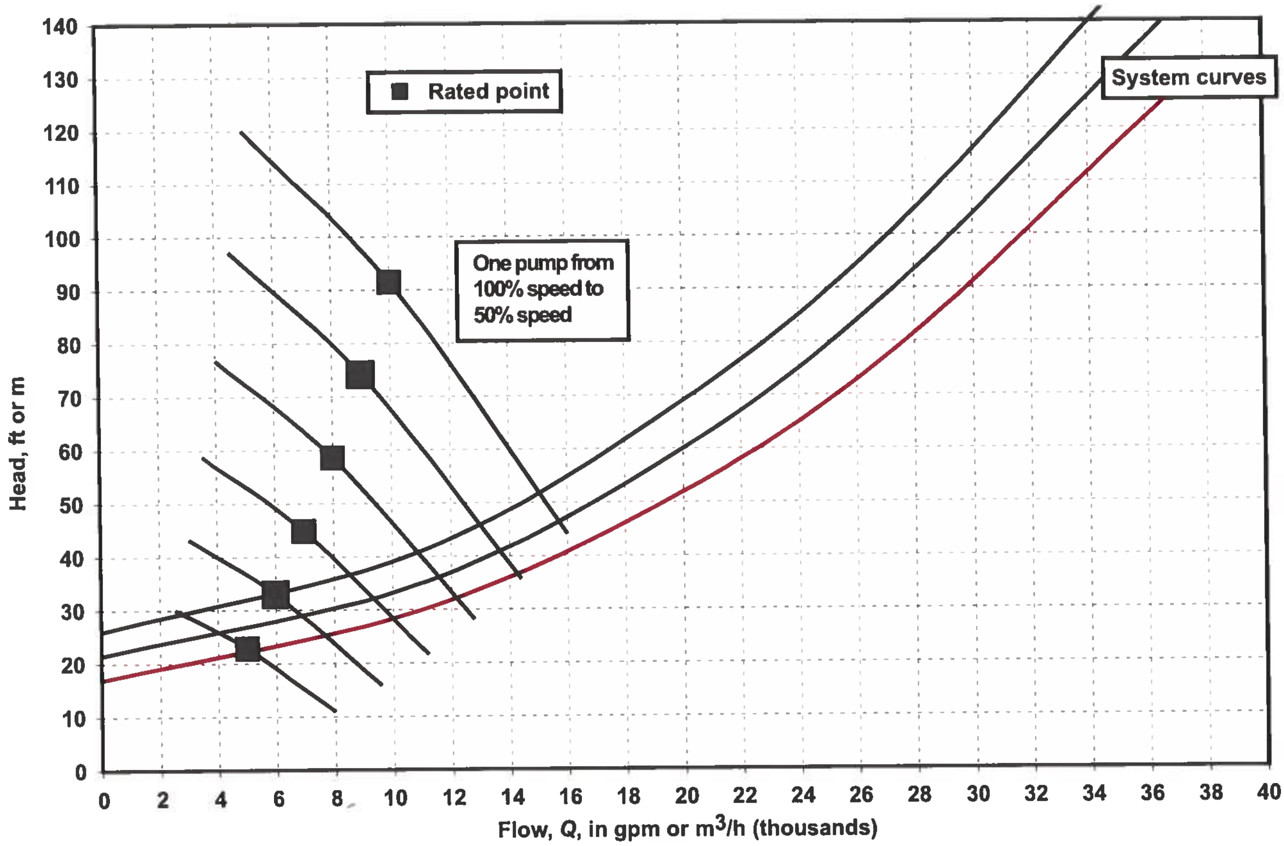


Figure K.3 — Multiple system curves, variable speed

Appendix L

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Appendix I

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Appendix M

Index

This appendix is not part of this standard, but is presented to help the user with factors referenced in the standard.

Note: an f. indicates a figure, and a t. indicates a table.

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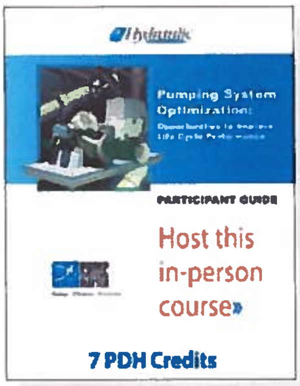

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