ANSI/HI 9.8-1998

Approved American National Standard

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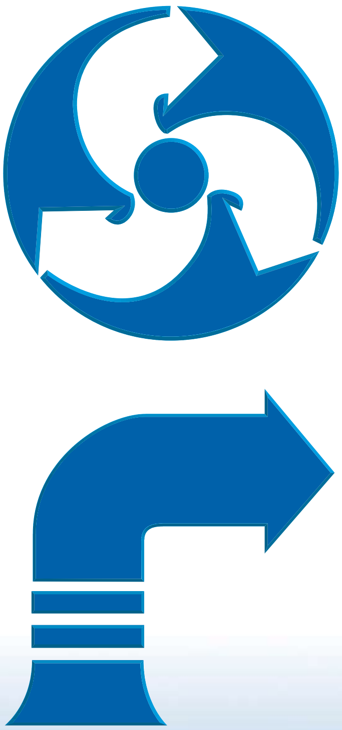

American National Standard for

Pump Intake Design

ANSI/HI 9.8-1998

Hydraulic Institute

6 Campus Drive
First Floor North
Parsippany, New Jersey
07054-4406
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Approved November 17, 1998

American National Standards Institute, Inc.

American National Standard

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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 and well-being of pump manufacturers and 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 Hydraulic Institute. It will direct all such questions 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, the point in question shall be referred to the Executive Committee of the Hydraulic Institute, which then shall act as a Board of Appeals.

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 canvas procedure.

Over the past several decades, long-term performance results for many different centrifugal and axial flow pumping facilities have become available. Based on some less than satisfactory results, the industry has recognized a need for updating the standard approaches to designing pump intake structures and suction piping. In response to this evolving need, the Hydraulic Institute has improved and expanded its recommendations for designing intake structures for centrifugal, vertical turbine, mixed-flow, and axial-flow pumps and added intake designs for solids-bearing liquids.

This standard is a result of the combined efforts of a balanced committee that was formed to reflect the perspectives of sump designers, hydraulic researchers, pump manufacturers, and end users. It replaces ANSI/HI 1.1-1.5-1994 Section 1.3.3.6 and ANSI/HI 2.1-2.5-1994 Section 2.3.5.

The intent of this current edition of the pump intake design standard is to provide designers, owners and users of pumping facilities a foundation upon which to develop functional and economical pumping facility designs. The material has been prepared with the deliberate goals of both increasing understanding of the subject and establishing firm design requirements.

Scope

This standard provides intake design recommendations for both suction pipes and all types of wet pits. While specific intake design is beyond the scope of the pump manufacturer's responsibility, their comments may be helpful to the intake designer.

Units of Measurement

Metric units of measurement are used; and corresponding US units appear in brackets. Charts, graphs and sample calculations are also shown in both metric and US units.

Since values given in metric units are not exact equivalents to values given in US 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

Consensus for this standard was achieved by use of the canvas method. The following organizations, recognized as having interest in the pump intake designs 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.

Ahlstrom Pumps, LLC
Alden Research Laboratory, Inc.
Bechtel Corporation
Black & Veatch
Brown & Caldwell
Camp Dresser & McKee
CH2M Hill
Chas S. Lewis & Co., Inc.
Crane Pump & Systems
David Brown Union Pump Company
DeWante & Stowell
Dow Chemical

Electric Power Research Institute
ENSR Consulting & Engineering
Equistar L.P.
Essco Pump
Fairbanks Morse Pump
Florida Power Corporation
Floway Pumps
Flowserve Corporation
Ingersoll-Dresser Pump
ITT A-C Pump
ITT Fluid Technology
ITT Goulds Pump
Iwaki Walchem Corp
J.P. Messina Pump and Hydraulics Consultant
John Crane, Inc.
Johnston Pump Company
Lawrence Pumps, Inc.
M. W. Kellogg
Malcolm Pirnie, Inc.
Marine Machinery Association
Montana State University
Montgomery Watson
MWI
National Pump Company
PACO Pumps
Patterson Pump Company
Price Pump
Raytheon Engineers & Constructors
Robert Bein, William Frost & Assoc.
Sewage & Water Board of New Orleans
Skidmore
Solutia, Inc.
South Florida Water Management District
Southern Company Services, Inc.
Sta-Rite Industries
Stone and Webster
Sulzer Binhham Pumps, Inc.
Summers Engineering, Inc.
Systecon, Inc.
Tennessee Valley Authority
US Bureau of Reclamation

Committee List

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

NAME	COMPANY	CATEGORY
Jack Claxton, Chairman	Patterson Pump Company	Producer
Stefan Abelin, Vice Chair.	ITT Flygt Corp.	Producer
William Beekman	Floway Pumps	Producer
Thomas Demlow	ENSR Consulting & Engineering	General Interest
Thomas Duncan	Southern Company Services, Inc.	User
Peter Garvin	Bechtel Corporation	General Interest
Herman Greutink	Johnston Pump Company	Producer
James Healy	Stone and Webster	General Interest
George E. Hecker	Alden Research Laboratory Inc.	General Interest
Joseph Jackson	Yeomans Chicago Corp.	Producer
Garr Jones	Brown & Caldwell	General Interest
Zan Kugler	South Florida Water Management District	User
James Leech	US Army Corps of Engineers	User
Frederick Locher	Bechtel Corporation	General Interest
Wilbur Norwood (Alternate)	Yeomans Chicago Corp.	Producer
Robert Sanks	Montana State University	General Interest
Gerald Schohl	Tennesse Valley Authority	User
Arnold Sdano	Fairbanks Morse Pump	Producer
G. Joseph Sullivan	Sewerage & Water Board of New Orleans	User
Zbigniew Czarnota (Alternate)	ITT Flygt Corp.	Producer

Major Revisions

Past Hydraulic Institute intake design standards have been based on the rated flow rate of the pump, while several other pump intake guidelines are based on dimensions determined from multiples of the inlet bell diameter.

Recognizing that a balance between these concepts may optimize the intake design, this edition is based upon:

- the pump intake bell outside diameter called “design diameter” or simply “D”
- an acceptable average velocity range across D (see Table 9.8.3)
- verification that the approach velocity does not exceed specified limits
- submergence “S” of pump intakes as a function of Froude number “F_D” and D

This edition consists of the “standard,” Section 9.8, Intake Design Standards, and several appendices. These appendices are included as educational information and are not part of the standard. Illustrations of “Not Recommended” designs have been eliminated, as they are too numerous to document properly.

Other major changes introduced by this standard are given below under each subject heading.

Rectangular Intakes

The dimensioning for rectangular plan intakes has been changed from a flow-based design to one based on D, as determined by the inlet bell velocity. A partitioned intake design is recommended over an open intake design.

Reference sections (*9.8.2.1 and 9.8.3.4*)

Formed Suction Intakes

This standard introduces recommendations for the formed suction inlet.

Reference sections (9.8.2.2)

Circular Intakes

This standard introduces recommendations for the appropriate use of circular wet wells for both clear and solids-bearing liquids, and it suggests specific configurations.

Reference sections (9.8.2.3 and 9.8.3.3)

Trench-Type Intakes

This standard introduces geometry for trench-type wet wells for both clear and solids-bearing liquids.

Reference sections (9.8.2.4 and 9.8.3.2)

Suction Tanks

Guidelines are provided for suction tank applications.

Reference section (9.8.2.5)

Barrel or Can and Submersible Vertical Turbine Intakes

Recommendations for barrel or can-type intakes and submersible vertical turbine intakes designs are introduced.

Reference section (9.8.2.6)

Unconfined Intakes

Guidelines are provided for unconfined intake applications.

Reference section (9.8.2.7)

Solids-Bearing Liquids Applications

In past editions of this standard, discussions of solids-bearing liquids were limited to advising designers to obtain specific recommendations from pump manufacturers. This standard provides recommendations for pump sump designs intended for solids-bearing liquids. It addresses the special considerations of keeping wet wells clean and maintaining minimum velocities. Specific recommendations for wet well geometries are provided.

Reference section (9.8.3)

Pump Suction Piping

The section on suction piping has been rewritten and condensed. It provides information and specific recommendations for suction piping design, suction headers, and design recommendations for solids-bearing liquids.

Reference section (9.8.4)

Model Testing

The discussion of sump model testing has been expanded to include:

- factors for determining when a model test is necessary
- scaling criteria for determining adequate model size and proper flow rates
- recommended instrumentation and testing methods
- acceptance criteria for wet well and suction piping hydraulic performance

Reference section (9.8.5)

Inlet Bell Diameter

When the bell diameter “D” has not been established, the standard uses a “Design Bell Diameter” based on an acceptable velocity range for determination of sump geometry.

Reference section (9.8.6)

Submergence

The submergence “S” of pump intakes is determined as a function of inlet bell Froude number “F_D” and D.

Submergence requirements for the bell or pipe intake, as calculated with this standard, are generally less than the values specified by the 13th edition, but more than those required by the 14th edition of the Hydraulic Institute standards.

Reference section (9.8.7)

Appendix

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

Appendices have been added to include:

a) Remedial Measures for Problem Intakes

b) Sump Volume (calculations with considerations given for cyclical operation of constant speed pumps)

c) Intake Basin Entrance Conditions

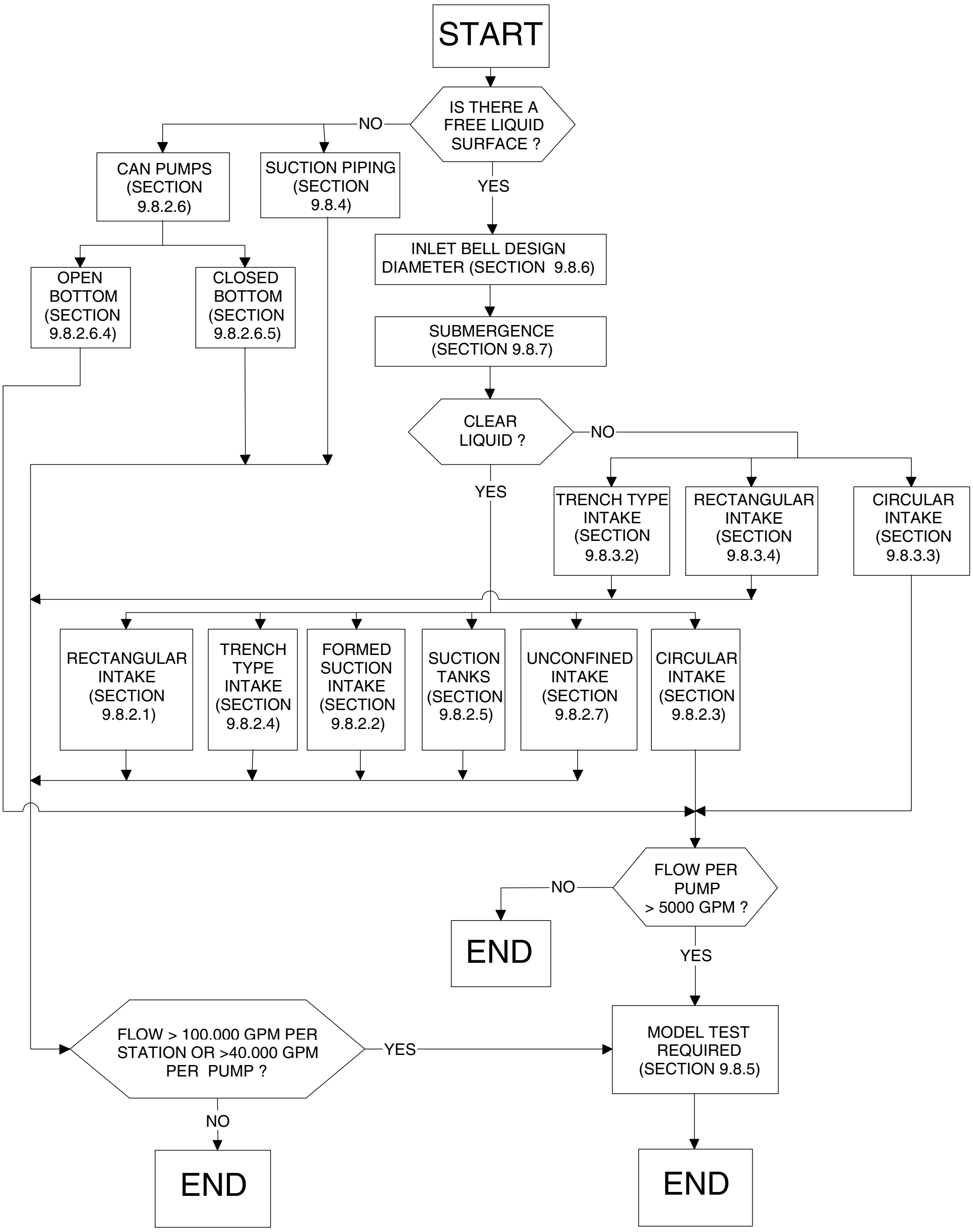
d) Bibliography

Disclaimers

This document presents accepted best practices based upon information available to the Hydraulic Institute as of the date of publication. Nothing presented herein is to be construed as a warranty of successful performance under any conditions for any application.

Flow Chart For Use Of Standard

NOTE: This flow chart 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.



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Pump Intake Design

9.8 Pump intake design

Metric units of measurement are used; and corresponding US units appear in brackets. Charts, graphs and sample calculations are also shown in both metric and US units.

Since values given in metric units are not exact equivalents to values given in US units, it is important that the selected units of measure be stated in reference to this standard. If no such statement is provided, metric units shall govern. See Section 9.8.8 for Glossary and Nomenclature.

In the application of this standard, the pump rated flow shall be used as the design flow for the basis of the intake design.

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
- Excessive pre-swirl of flow entering the pump
- Non-uniform spatial distribution of velocity at the impeller eye
- Excessive variations in velocity and swirl with time
- Entrained air or gas bubbles

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, large pumps and axial flow pumps (high specific speed) are more sensitive to adverse flow phenomena than small 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. Typical symptoms of adverse hydraulic conditions are reduced flow rate, head, effects on power, and increased vibration and noise.

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 9.8.5.6.

If an intake is designed to a geometry other than that presented in this standard, and this design is shown by prototype or model tests, performed in accordance with Section 9.8.5, to meet the acceptance criteria in Section 9.8.5.6, then this alternative design shall be deemed to comply with this standard.

9.8.2 Intake structures for clear liquids

9.8.2.1 Rectangular intakes

This section is applicable to wet pit pumps. This section also applies to the intakes for dry pit pumps with less than five diameters of suction piping immediately upstream from the pump (see Section 9.8.4).

9.8.2.1.1 Approach flow patterns

The characteristics of the flow approaching an intake structure is one of 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 upon 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 9.8.5 provides recommendations for analyzing departures from this ideal condition based upon a physical hydraulic model study.

9.8.2.1.2 Open vs. 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. Adverse flow patterns can frequently occur if dividing walls are not used. For pumps with design flows greater than 315 l/s (5,000 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, can create a high-velocity jet 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, 6D, (see Section 9.8.6) 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 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:

- 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:

$$F_D = V/(gD)^{0.5} \qquad (9.8.2.1\text{-}1)$$

Where:

F_D = Froude number (dimensionless)

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

D = Outside diameter of bell or 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),

$$S = D(1+2.3F_D) \qquad (9.8.2.1\text{-}2)$$

where the units of S are those used for D. Section 9.8.7 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 9.8.6). 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 9.8.1. The dimension variables and their recommended values are defined in Table 9.8.1.

Through-flow traveling screens generally do not clog to the point where flow disturbances occur. Therefore, they may be located such that Y is 4.0D or more in dimension. For non-selfcleaning trash racks or stationary screens, the dimension Y shall be increased to a minimum of 5.0D. Care must be taken to ensure that clogging does not occur to the extent that large non-uniformities in the pump approach flow will be generated.

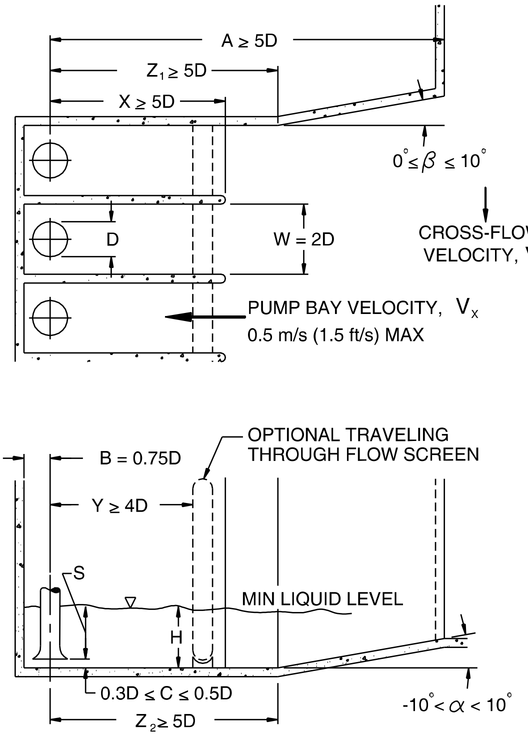


Figure 9.8.1 — Recommended intake structure layout

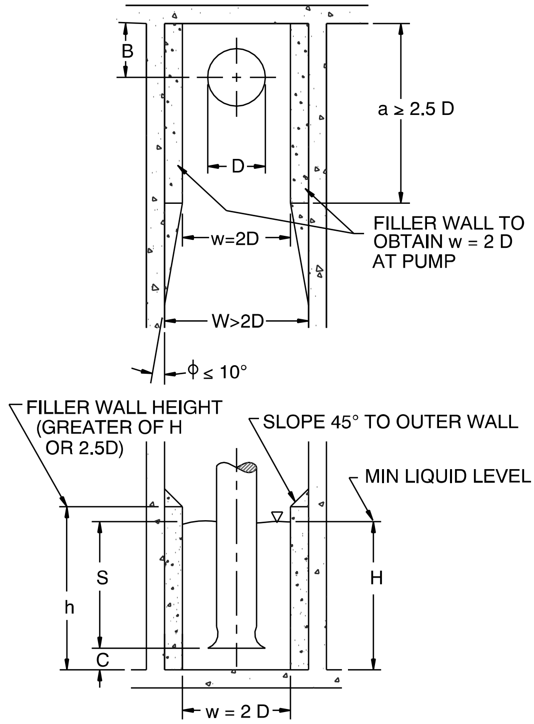


Figure 9.8.2 — Filler wall details for proper bay width

The effectiveness of the recommended pump bay dimensions depends upon the characteristics of the flow approaching the structure, and upon 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 conditions.

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 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 due to 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.

For pumps with design flows of 315 l/s (5,000 gpm) or less, no partition walls between pumps are required, and the minimum pump spacing shall be 2D.

Table 9.8.2 provides a sequence of steps to follow in determining the general layout and internal geometry of a rectangular intake structure.

9.8.2.2 Formed suction intakes

9.8.2.2.1 General

This standard applies to formed suction intakes. The standard utilizes the “TYPE 10” design developed by the US Army Corps of Engineers (ETL No. 110-2-327). The formed suction intake (FSI) may eliminate the need for the design of sumps with approach channels and appurtenances to provide satisfactory flow to a pump. The 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 which will affect to some extent the system curve calculations, and the net positive suction head (NPSH) available to the pump impeller, typically located near the FSI exit.

9.8.2.2.2 Dimensions

The FSI design dimensions are indicated in Figure 9.8.3. The wall shown in Figure 9.8.3 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.

9.8.2.2.3 Application standards

Minimum submergence (see Section 9.8.7) is calculated as follows:

$$S/D = 1.0 + 2.3\,F_D$$

Where:

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

Table 9.8.1 — Recommended dimensions for Figures 9.8.1 and 9.8.2

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
a	Length of constricted bay section near the pump inlet	a = 2.5D minimum
B	Distance from the back wall 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 9.8.6
H	Minimum liquid depth	H = S + C
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 9.8.7 for detailed discussion on determining minimum submergence)
W	Pump inlet bay entrance width	W = 2D minimum
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
Y	Distance from pump inlet bell centerline to the through-flow traveling screen	Y = 4D minimum. Dual-flow screens require a 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	α = –10 to +10 degrees
β	Angle of wall convergence	β = 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	ϕ = 10 degrees maximum

[a] Cross-flow is considered significant when $V_C > 0.5\ V_X$ average

D is the diameter of a circle having an area equivalent to the rectangular FSI opening, $D = [(4/\pi) WH_f]^{0.5}$

V used in F_D, is the average velocity through the FSI opening

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. 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 the standard because of complex flow patterns; such designs require a model study. Circular pump sumps for flows exceeding 315 l/s (5000 gpm) per pump require a model test.

Table 9.8.2 — 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 9.8.5.1 if a hydraulic 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 Figure 9.8.25 to obtain the inlet bell design diameter
4	Determine the bell-floor clearance, see Figure 9.8.1. A good preliminary design number is 0.5D.
5	Determine the required bell submergence, using the relationship in Section 9.8.7.
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.
8	Check the pump bay velocity for the maximum single-pump flow and minimum liquid depth with the bay width set to 2D. 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 2D, then decrease bay width in the vicinity of the pumps according to Figure 9.8.2.
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 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 hydraulic model study is required (see Section 9.8.5.1, Need for Model Study).
12	If the final selected pump bell diameter and inlet velocity is within the range given in Section 9.8.6, the sump dimensions (developed based on the inlet bell design diameter) need not be changed and will comply with these standards.

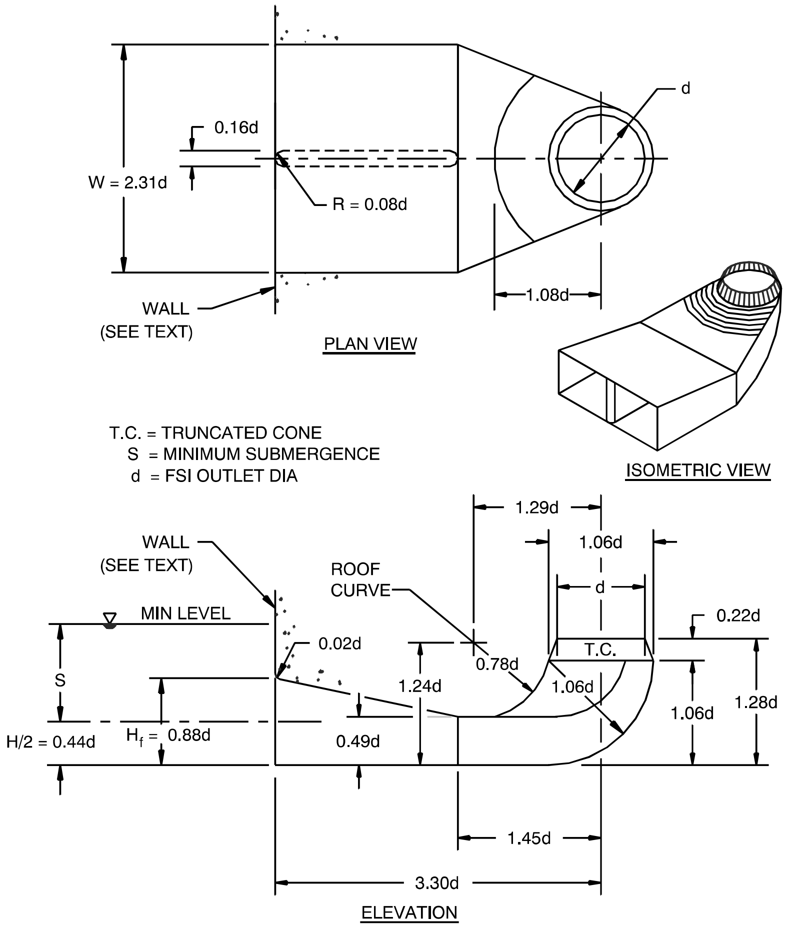


Figure 9.8.3 — Type 10 formed suction intake

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 9.8.7 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 0.3D and 0.5D.

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 0.25D or at least 100 mm (4 inches).

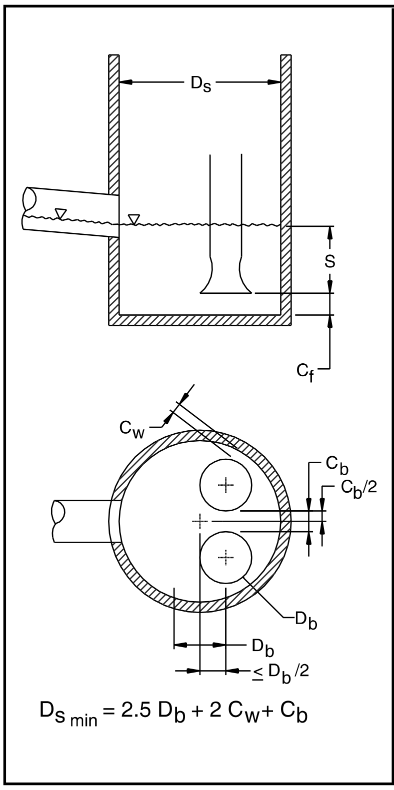


Figure 9.8.4A — Wet pit duplex sump with pumps offset

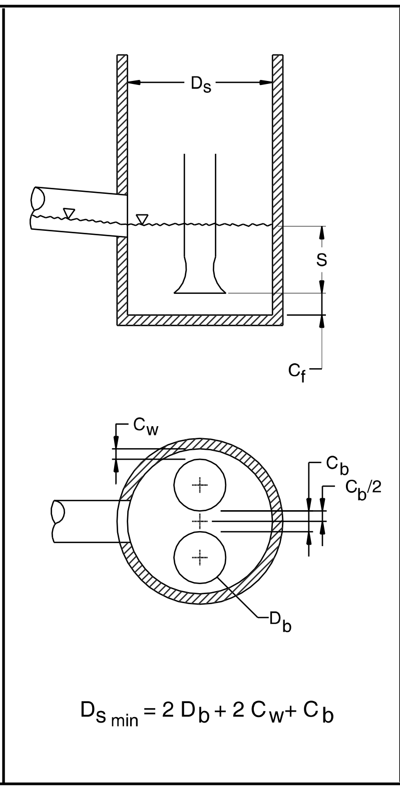


Figure 9.8.4B — Wet pit duplex sump with pumps centerline

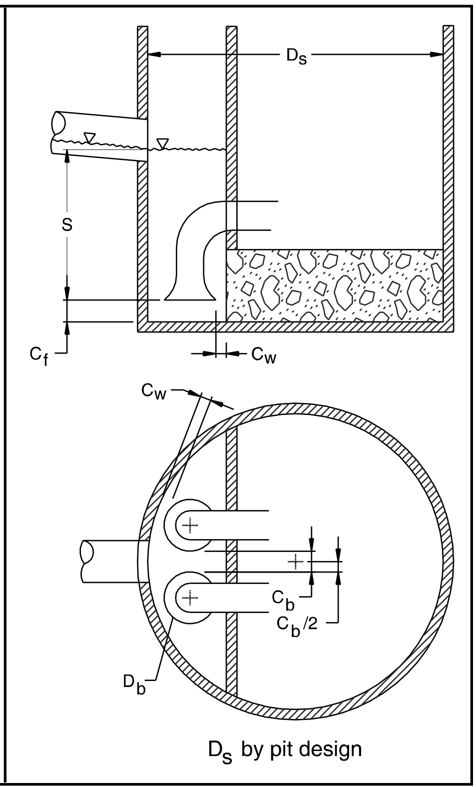


Figure 9.8.4C — Dry pit/wet pit duplex sump

9.8.2.3.2.4 Inlet bell clearance C_b

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

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 9.8.4A through 9.8.5C.

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.

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 and normal 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.

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 9.8.6 and 9.8.7, an abrupt transition is used to create a confined trench for the location of the pump inlets.

While only limited 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). 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).

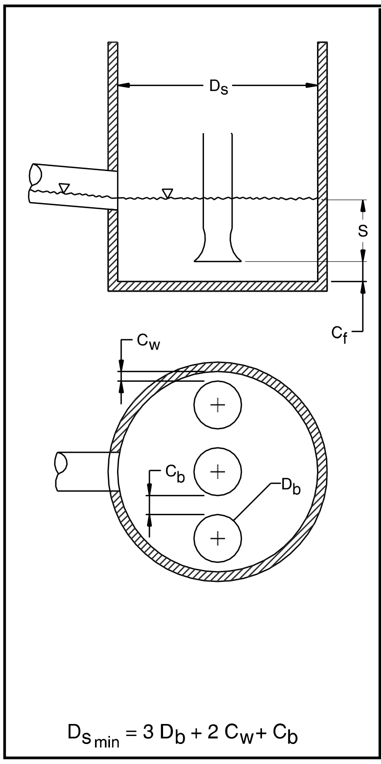


Figure 9.8.5A — Wet pit triplex sump, pumps in line

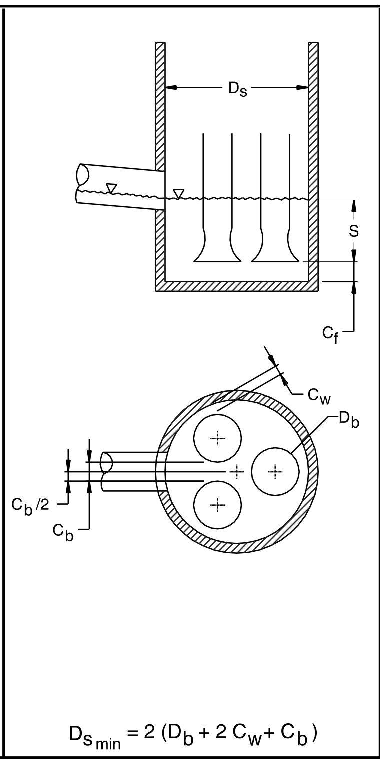


Figure 9.8.5B — Wet pit triplex sump, compact

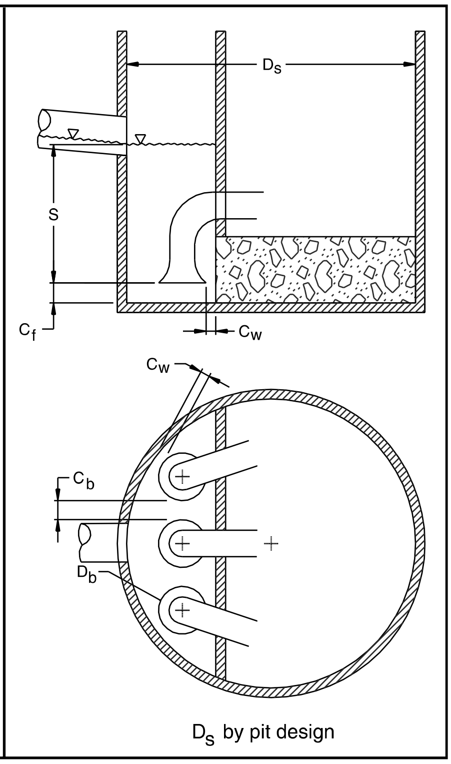


Figure 9.8.5C — Dry pit/wet pit triplex sump

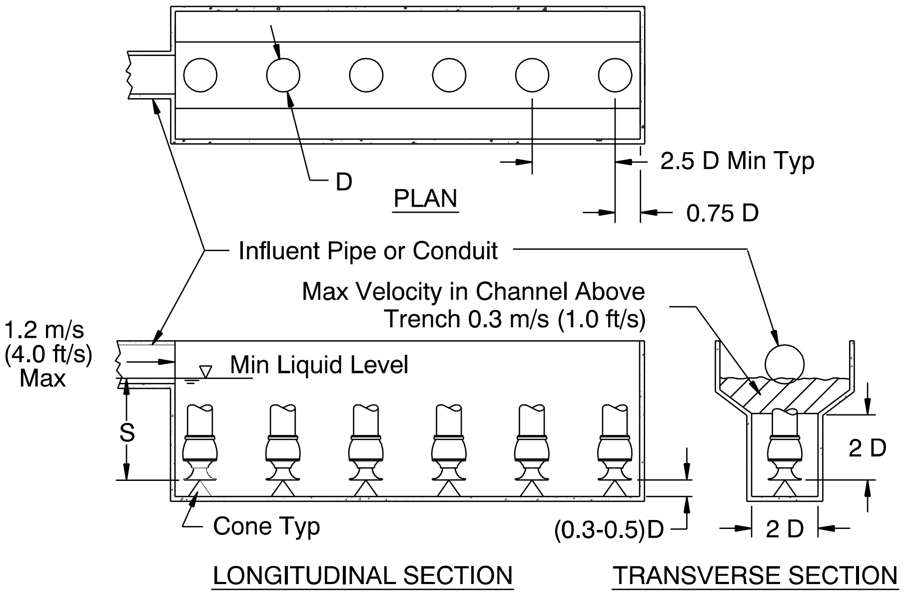


Figure 9.8.6 — Trench-type wet well

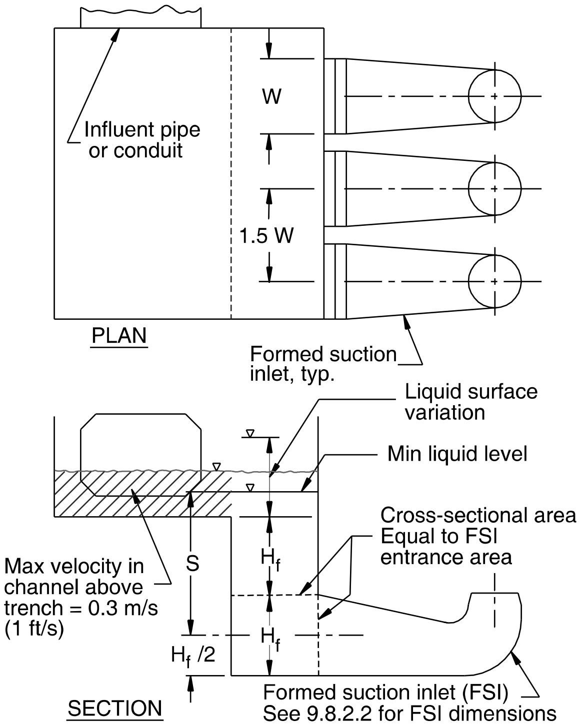


Figure 9.8.7 — Trench-type wet well with formed suction inlet

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 elevation of the influent channel or conduit.

9.8.2.4.3 Orientation

It is preferable to align the long axis of the wet well with the centerline of the upstream conduit or channel. Offset centerlines are not recommended. The approach conduit can be normal to the axis of the trench as long as careful attention is given to the approach velocity. The approach velocity is limited for each orientation. See Section 9.8.2.4.4.

9.8.2.4.4 Approach velocity

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. If the axis of the channel or conduit is normal to the axis of the trench, a maximum velocity of 0.6 m/s (2.0 ft/s) is recommended.

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 9.8.6.

9.8.2.4.6 Intake submergence

See Submergence, Section 9.8.7

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 0.75D.

9.8.2.4.8 Floor clearance

Clearance between the floor of the trench and the rim of the inlet bell shall be 0.3D to 0.5D. Floor cones are recommended under each of the pump inlet bells. See Paragraph 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 2.5D.

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 Suction tanks

9.8.2.5.1 General

This standard applies to partly filled tanks, pressurized or non-pressurized, 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

9.8.2.5.2 Objectives

The purpose of this standard 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 flow irregularities are dissipated.

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 Principles

See Figure 9.8.8, 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

$$S/D = 1.0 + 2.3\,F_D$$

Where:

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

D = outlet fitting diameter

V = outlet fitting velocity

g = acceleration of gravity

For further discussion of submergence, see Section 9.8.7

9.8.2.5.5 Application options

Whereas Figure 9.8.8, examples 1 through 4 show how the calculated submergence value is to be applied, Figure 9.8.9, 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 9.8.9, 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.12, should be considered.

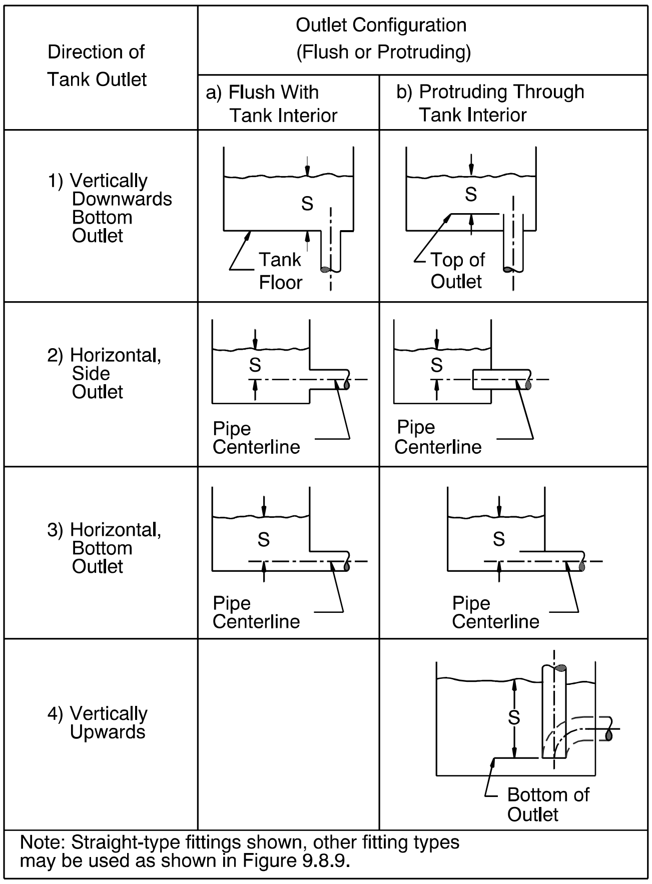


Figure 9.8.8 — Datum for calculation of submergence

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.

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.

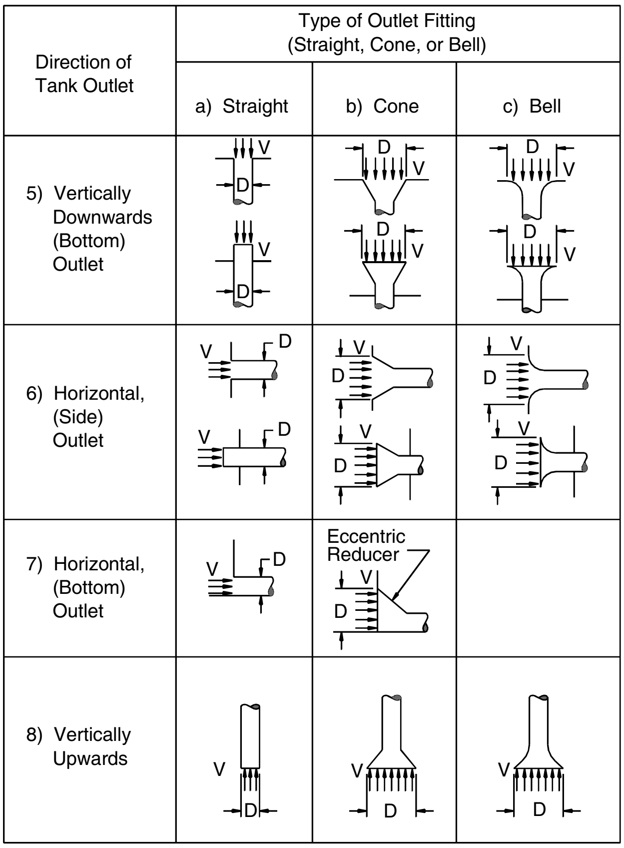


Figure 9.8.9 — Definitions of V and D for calculation of submergence

9.8.2.6 Can and submersible vertical turbine pump intakes (clear liquids)

9.8.2.6.1 General

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

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 less than 5000 specific speed (US 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° turning vane elbow and vortex suppressor.

9.8.2.6.4 Open bottom can intakes (Figure 9.8.10)

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 draw down 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 model test.

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° vaned elbow. Intake model tests for pump flows above 315 l/s (5000 gpm) are recommended.

The 90° turning vane inlet diameter (D) shall be sized to limit the inflow velocity to 1.5 m/s (5.0 ft/s). Attachment of a 90° 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 which 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.

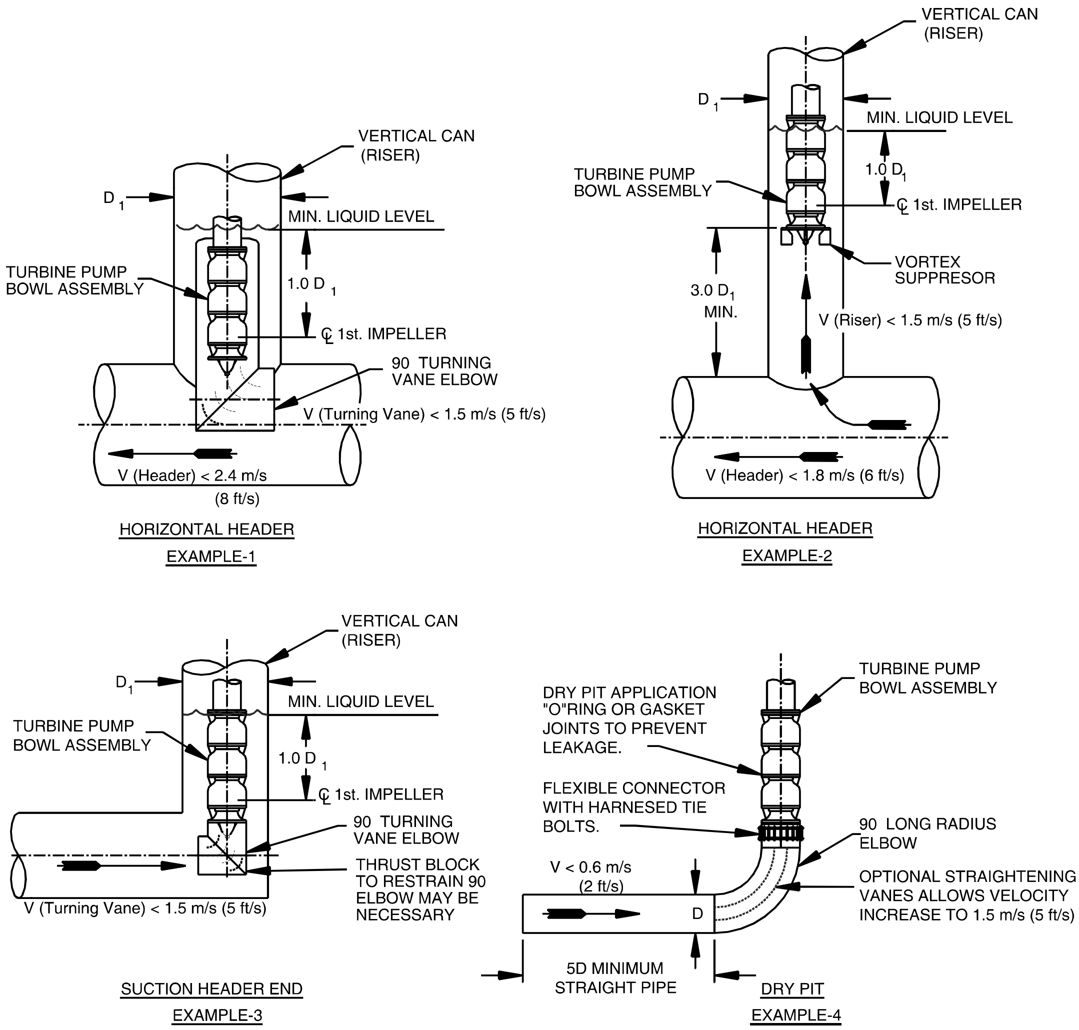


Figure 9.8.10 — Open bottom can intakes (pumps less than 315 l/s [5000 gpm])

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

Example 4 - A 90° 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

The most typical can pump configurations are closed bottom. See Figure 9.8.11 for design recommendations with various inlet pipe positions relative to the bell.

Centering of the pump in relation to the can to avoid rotational flow being generated by non-uniform flow around a non-concentric pump is of particular importance. Care must be taken during installation of the

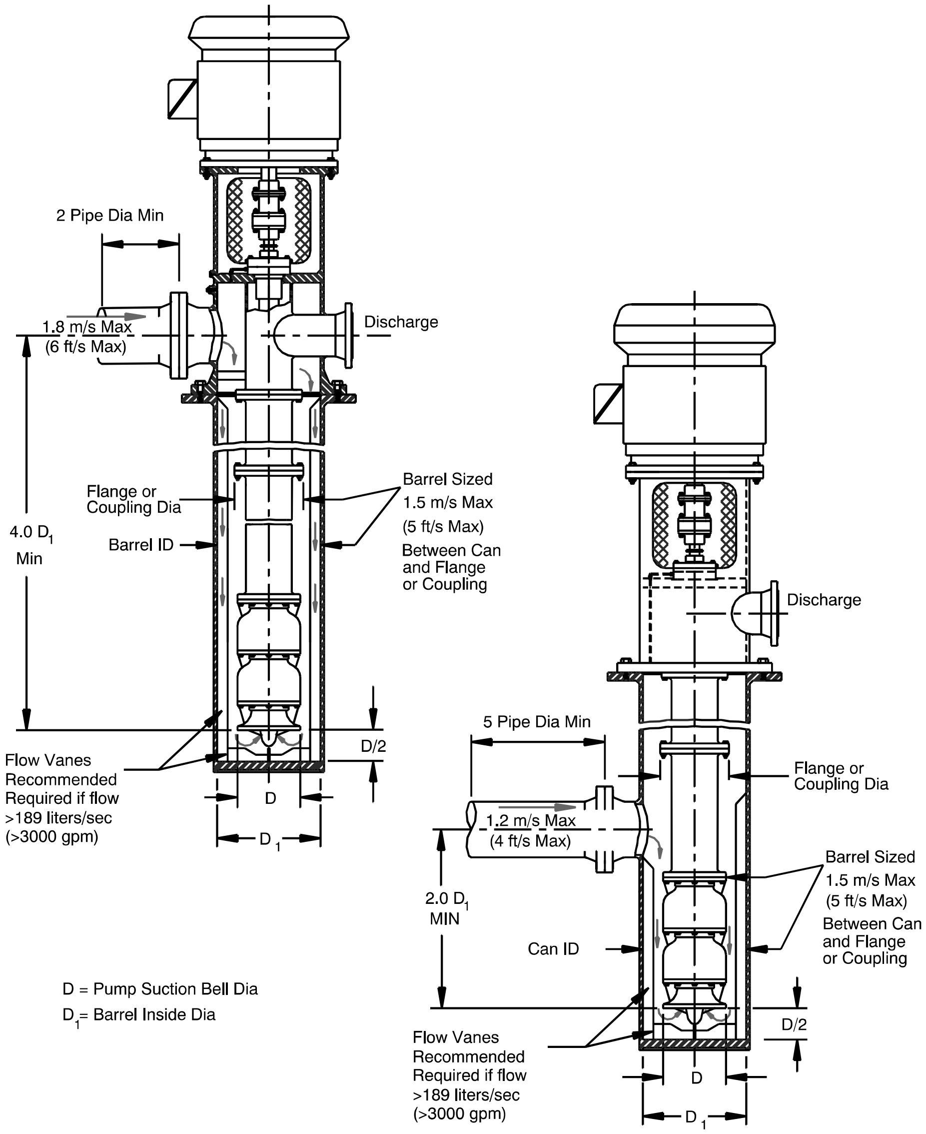


Figure 9.8.11 — Closed bottom can

barrel to assure concentricity of pump to barrel. 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. 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.

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.

The intake piping must be large enough to limit draw down below the recommended minimum liquid level to a period of less than 3 seconds during start-up.

9.8.2.6.6 Submersible pumps (well motor type)

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

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 assure 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, while allowing for venting of air from the shroud.

The intake piping must be large enough to limit draw down below the recommended minimum liquid level to a period of less than 3 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).

9.8.2.7 Unconfined intakes

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

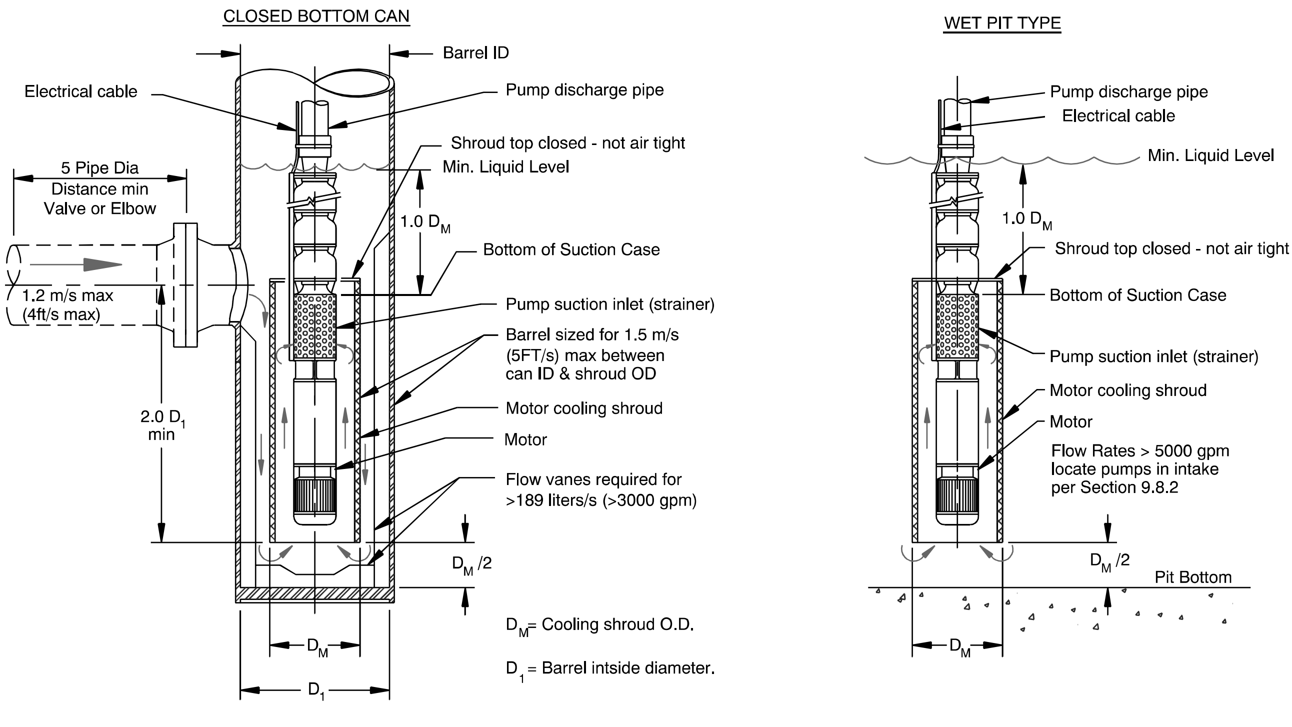


Figure 9.8.12 — Submersible vertical turbine pump

channels, intakes on lakes and pumps located on platforms for seawater systems.

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.

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 5D 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 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 which 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

$$S/D = 1.0 + 2.3\,F_D$$

Where:

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

D = outlet fitting diameter

V = outlet fitting velocity

For further discussion of submergence, see Section 9.8.7.

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.

9.8.3.1.1 Scope

This standard 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 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 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. Trench-type wet wells (see Section 9.8.2.4) and circular plan wet wells (see Section 9.8.2.3), with some modifications as presented in this section, have been found to be suitable for this purpose.

9.8.3.1.4 Vertical transitions

Transitions between levels in wet wells for solids-bearing liquids shall be at steep angles (60° minimum for concrete, 45° 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 Figures 9.8.13 and 9.8.14.

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 9.8.17.

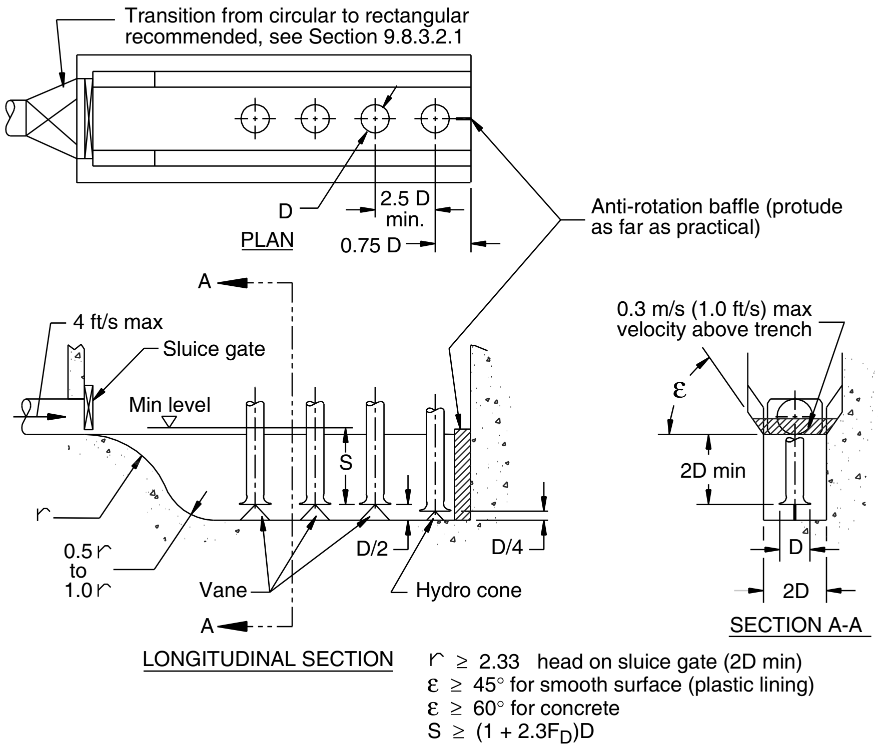


Figure 9.8.13 — Open trench-type wet well

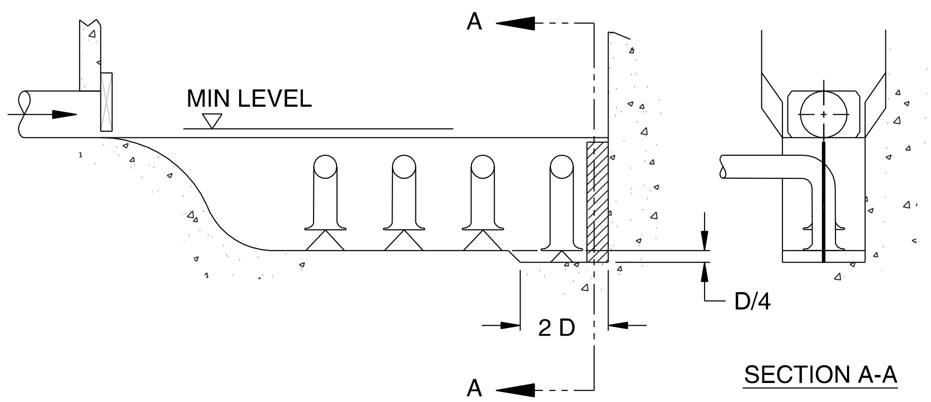


Figure 9.8.14 — Open trench-type wet well for pumps sensitive to loss of prime

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 is dependent 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.

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 have been successfully 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 9.8.3.2.5 and Figure 9.8.13 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, because pump discharge equals inflow. Consequently, the water level in the wet well can be made to match the water level in the upstream conduit.

When constant speed pumps are used, the water 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 inches) 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 water level, the velocity in the approach pipe is supercritical, thus leaving a large part of the cross section empty for storage as the water level rises. The design of approach pipes is not a part of these standards, but the essentials of design are given in Appendix C.

9.8.3.2.3 Open trench design

See Figure 9.8.13 for the arrangement of an open trench wet well.

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 need be large enough only for a smooth transition to horizontal flow; 0.5 r to 1.0 r 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 9.8.13 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 D/2 above the floor of the wet well trench. The inlet for the last pump (farthest from the wet well inlet) shall be located D/4 above the floor of the trench. See Figure 9.8.13.

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 D/4 provided the floor near the intake is lowered by the same amount. See Figure 9.8.14 for this arrangement. All other dimensions and velocities for this arrangement shall comply with those given in Figure 9.8.13.

9.8.3.2.3.3 Inlet splitters and cones

Fin-type floor 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 9.8.13.

9.8.3.2.3.4 Anti-rotation baffle

An anti-rotation baffle at the last pump inlet, shown in Figure 9.8.13, is needed to ensure satisfactory performance during the cleaning cycle. The anti-rotation baffle should protrude towards the pump as far as practicable.

9.8.3.2.3.5 Cleaning procedure

Trench-type wet wells for solids-bearing liquids can be cleaned readily by stopping all pumps to store enough liquid for the cleaning process in the upstream conduit. When sufficient liquid is available, flow into the wet well should be limited to approximately 75 percent of the flow rate of the last pump in the trench by adjusting the sluice gate. The pumps are operated to lower the liquid level to a minimum as rapidly as possible such that the stored liquid volume is sufficient to complete the cleaning cycle. As the liquid level in the wet well falls, the liquid attains supercritical velocity as it flows down the ogee spillway, and a hydraulic jump is formed at the toe. As the hydraulic jump moves along the bottom of the trench, the jump and the swift currents suspend the settled solids, causing them to be pumped from the trench. As the hydraulic jump passes under each pump intake, the pump loses prime and should be stopped.

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. Additionally, the bottom of the wet pit shall have sloped surfaces around the inlet bells or pumps, as shown in Figures 9.8.15 and 9.8.16.

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.

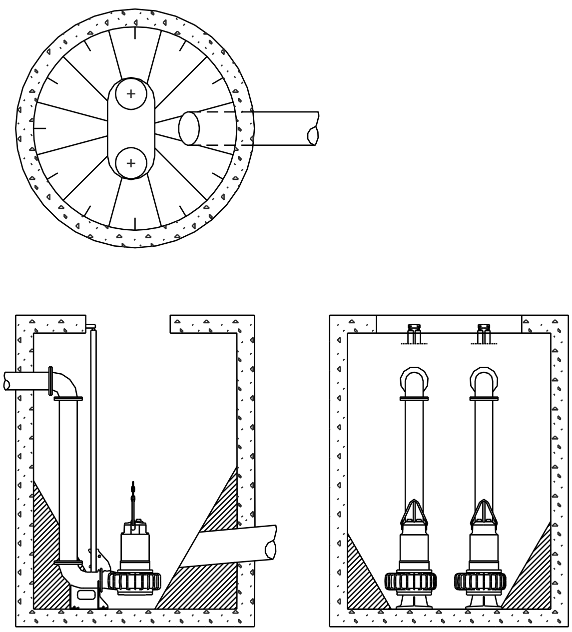


Figure 9.8.15 — Circular wet pit with sloping walls and minimized horizontal floor area (submersible pumps shown for illustration)

9.8.3.3.3 Cleaning procedure

The frequency of cleaning cycles is dependent 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 removal of floating solids can only be accomplished when the liquid surface area is at a minimum and the pump intake submergence is low enough (0.5 to 1.0 D) to create a strong surface vortex (number 4 to number 6 in Figure 9.8.23). Such a submergence level is lower than that recommended in Section 9.8.7. Pumping under these severe conditions will cause noise, vibration, and high loads on the impeller and hence should be limited to brief, infrequent periods (refer to pump manufacturer's recommendation). The pumps should be stopped as soon as they lose prime, or as soon as the sump is free of floating debris.

9.8.3.4 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.

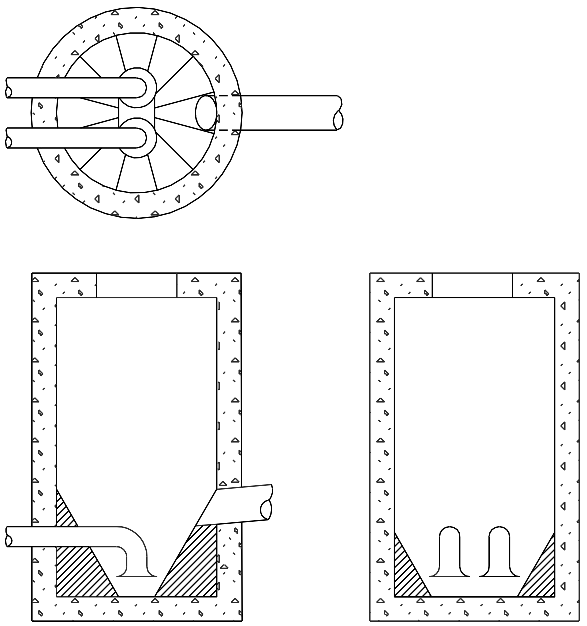


Figure 9.8.16 — Circular wet pit with sloping walls and minimized horizontal floor area (dry pit pumps)

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. Such a means should be thoroughly investigated before a design is begun.
- Violent mixing to suspend sediments while the mixture is being removed by the main pumps. These methods include:
  1) Use of submerged mixers.
  2) Bypassing part of the pump discharge back into the wet well.
  3) Connecting the force main to a valve and then to 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 in order to minimize the amount of solids settling out of the flow.

See Figure 9.8.17 for the arrangement of a confined wet well.

9.8.3.4.4.1 Suction inlet clearance

All suction inlets shall be located D/4 above the floor of the wet well. The side walls 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 the Figure 9.8.17, 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 draw down 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 percent 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.

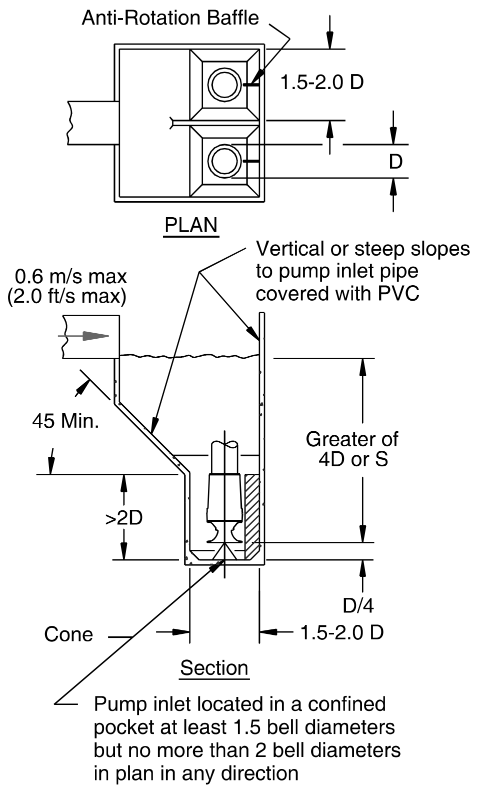


Figure 9.8.17 — Confined wet wall design

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 is dependent on local conditions, and therefore should be determined by experience at the site. Generally, the cleaning operation will take less than 5 minutes to perform and the duration between cleaning cycles would typically be 1 to 2 weeks.

9.8.4 Pump suction piping

9.8.4.1 General

This section provides information and design recommendations for suction piping, required for all pumping applications, except where the pump inlet is immersed in the liquid. Proper design of suction piping is critical in that it determines the uniformity of flow delivered to the pump. Disturbed inflow causes deterioration of pump performance and may shorten pump life due to vibration and cavitation. Discharge piping has virtually no effect on pump performance other than the head loss that it creates. In this section, the term “pipe fittings” refers to all types of plumbing fittings, such as bends, reducers, tee and wye connections, and all types of valves.

This standard is intended to provide design recommendations such that the pump will receive inflow of sufficient uniformity to perform its intended duty. Other piping considerations, such as head loss, material selection, costs, and space requirements also need to be considered and are not covered here.

9.8.4.2 Principles

The ideal flow entering the pump inlet should be of a uniform velocity distribution without rotation and stable over time. This ideal flow is often referred to as undisturbed flow, and it can be achieved by controlling pipe lengths and the type and location of fittings in the suction piping system. The suction piping should be designed such that it is simple with gentle transitions if changing pipe sizes. Transitions resulting in flow deceleration at the pump shall not used.

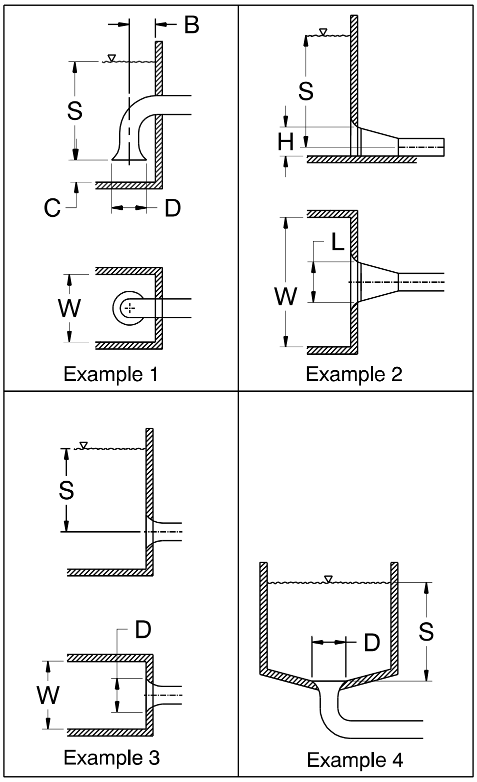


Figure 9.8.18 — Common intakes for suction piping showing submergence datum references

The velocities recommended in Section 9.8.4.3 shall be adhered to while keeping in mind that higher velocities increase head loss and thus decrease the NPSH available at the pump inlet.

The effect of disturbed flow conditions at the inlet bell, i.e., at the beginning of the suction piping, tend to diminish with distance. Short suction piping is less effective in moderating disturbances before the flow reaches the pump. Good inflow conditions at the inlet bell exists if the intake is designed following recommendations in other parts of this standard. See Figure 9.8.18. The recommended inlet bell velocity is specified in Table 9.8.3.

Part of the suction piping system can be subjected to pressures below atmospheric. It is, therefore, important to ensure that all fitting joints are tight, because air entrainment on the suction side may cause a reduction in pump performance and can be difficult to detect. Manifolds and suction headers are covered in Section 9.8.4.3.1.

Table 9.8.3 — Acceptable velocity ranges for inlet bell diameter "D"

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 9.8.25A for corresponding inlet diameters (OD), calculated according to $D = [Q/(785V)]^{0.5}$

Pump Flow Range Q, gpm	Recommended Inlet Bell Design Velocity, ft/s	Acceptable Velocity Range, ft/s
< 5,000	V = 5.5	$2 \le V \le 9$
≥ 5,000 < 20,000	V = 5.5	$3 \le V \le 8$
≥ 20,000	V = 5.5	$4 \le V \le 7$

NOTE: See Figure 9.8.25B for corresponding inlet diameters (OD), calculated according to $D = (0.409Q/V)^{0.5}$

9.8.4.3 Recommendations

The maximum recommended velocity in the suction piping is 2.4 m/s (8.0 ft/s). Velocities may be increased at the pump suction flange by the use of a gradual reducer. Higher velocities are acceptable providing the piping design delivers a smooth inlet flow to the pump suction as required in Section 9.8.5.6. The velocity in the suction piping should be constant or increasing as the flow approaches the pump.

For many common solids-bearing liquids, a velocity of about 1.0 m/s (3.0 ft/s) is required to prevent sedimentation in horizontal piping. A velocity as low as 0.6 m/s (2.0 ft/s) is generally sufficient for organic solids.

There shall be no flow disturbing fittings (such as partially open valves, tees, short radius elbows, etc.) closer than five suction pipe diameters from the pump. Fully open, non-flow disturbing valves, vaned elbows, long radius elbows and reducers are not considered flow disturbing fittings (refer to Figures 9.8.19 and 9.8.20).

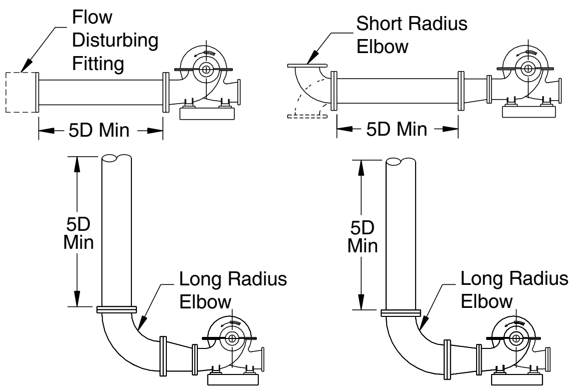


Figure 9.8.19 — Recommended suction piping near pump, all pump types (D = pipe diameter)

The suction pipe size is usually a larger diameter than the suction fitting on the pump. In such cases, a concentric or eccentric reducer is fitted to accommodate the difference in pipe size. For horizontal suction piping, the flat side of an eccentric reducer shall be located on the top. For vertical piping without bends near the pump, a concentric reducer is recommended.

9.8.4.3.1 Suction headers

A suction header, also called a suction manifold, is required when two or more pumps are fed from one common suction intake. Take-offs directly opposite each other are not allowed. The maximum velocity allowed in the suction header is 2.4 m/s (8.0 ft/s). If the ratio of the take-off diameter to the header diameter is equal to or greater than 0.3, then the minimum spacing between take-offs is 2 header diameters. If that same ratio is less than 0.3, the minimum spacing between take-offs is 3 take-off diameters. See Figure 9.8.22.

9.8.4.3.2 Submergence

For submergence of the suction header intake bell, see Section 9.8.7 and Figure 9.8.18 for calculation methods and datum references for S and D.

9.8.5 Model tests of intake structures

9.8.5.1 Need for 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 piping designs and to derive acceptable intake sump or piping designs. Considering the cost for a model study, an evaluation

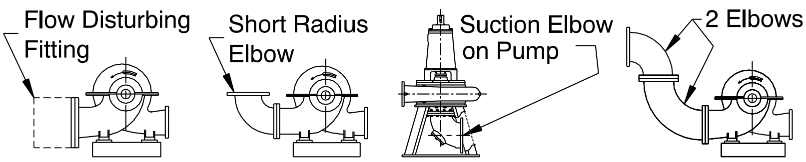


Figure 9.8.20 — Examples of suction pipe fittings near pump that require approval of the pump manufacturer

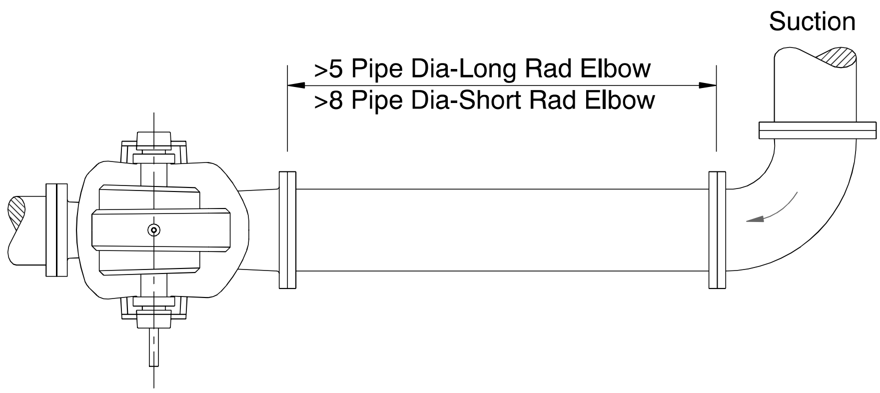


Figure 9.8.21 — Recommended suction piping for double suction pumps with the elbow in the same plane as the impeller shaft

is needed to determine if a model study 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 (bay width, bell clearances, side wall angles, bottom slopes, distance from obstructions, the bell diameter or piping changes, etc.) that deviates from this design standard.
- Non-uniform or non-symmetric 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).
- The pumps of an open bottom barrel or riser arrangement have flows greater than 315 l/s (5000 gpm) per pump (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 ten times the cost of a model study.

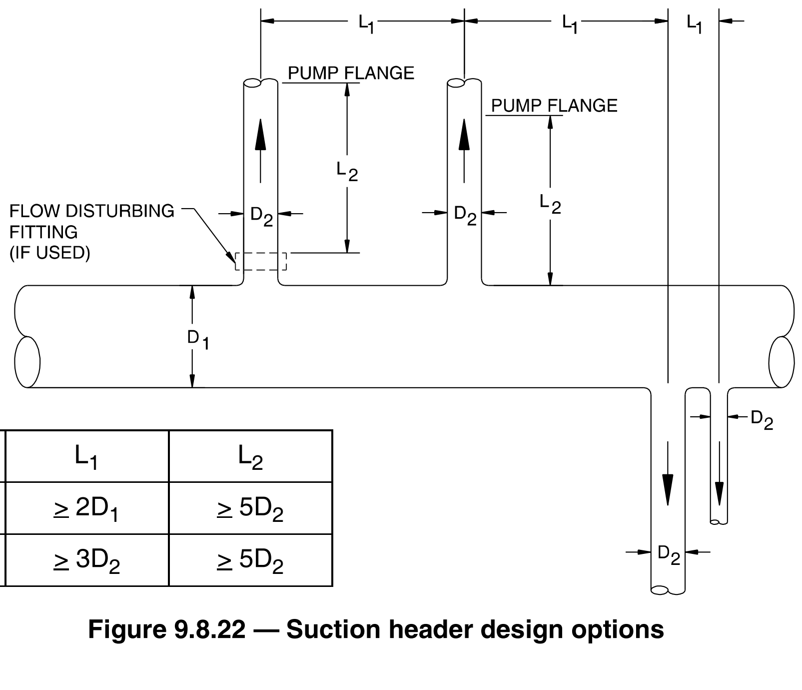
When evaluating the indirect impacts of inadequate performance or pump failures, the probability of failure may be considered, such as by comparing the proposed intake design to other intakes of essentially identical design and approach flow which operate successfully. The model study shall be conducted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

9.8.5.2 Model objectives

Adverse hydraulic conditions that can affect pump performance include: free and sub-surface vortices, swirl approaching the pump impeller, flow separation at the pump bell, and a non-uniform 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. Sub-surface vortices also have low core pressures and are closer to the impeller. Strong vortex cores may induce fluctuating forces on the impeller and cavitation. Sub-surface 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.

Pre-swirl 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.



D_2/D_1	L_1	L_2
≥ 0.3	$\geq 2D_1$	$\geq 5D_2$
< 0.3	$\geq 3D_2$	$\geq 5D_2$

Figure 9.8.22 — Suction header design options

A reasonably uniform axial velocity distribution in the suction flow (approaching the impeller) is assumed in the pump design, and non-uniformity 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.

9.8.5.3 Model similitude and scale selection

Models involving a free surface are operated using Froude similarity since 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:

$$F = u/(gL)^{0.5} \qquad (9.8.5\text{-}1)$$

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:

$$F_r = F_m/F_p = 1 \qquad (9.8.5\text{-}2)$$

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

In 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:

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

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 $uD/\nu = R$, the Reynolds number, and surface tension effects are indicated by $u^2D/(\sigma/\rho) = W_e$, 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 uD/Γ, $u/(gD)^{0.5}$, and 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 inches), a minimum liquid depth of at least 150 mm (6 inches), and a pump throat or suction diameter of at least 80 mm (3 inches) 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:

$$V_r = V_m / V_p = L_r^{0.5} \quad (9.8.5\text{-}3)$$

$$Q_r = Q_m / Q_p = L_r^2 V_r = L_r^{2.5} \quad (9.8.5\text{-}4)$$

$$T_r = T_m / T_p = L_r / V_r = L_r^{0.5} \quad (9.8.5\text{-}5)$$

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 = uDP/ν, 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.

9.8.5.4 Model scope

Selection of the model boundary is extremely important for proper simulation of flow patterns at the pump. As the approach flow non-uniformities contribute significantly to the circulation causing pre-swirl 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 up to the bell throat (section of maximum velocity) shall be scaled, including any hub located between the bell entrance and the throat. 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 multi-stage pumps, in which case the external shape may affect flow patterns approaching the inlet bell. The impeller is not included in hydraulic 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.

9.8.5.5 Instrumentation and measuring techniques

Unless agreed upon circumstances indicate otherwise, the following measurements shall be made. The extent of the measurements is summarized in Section 9.8.5.7, Test Plan, below.

Flow: The outflow from each simulated pump shall be measured with flow meters. 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 9.8.23A, 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.

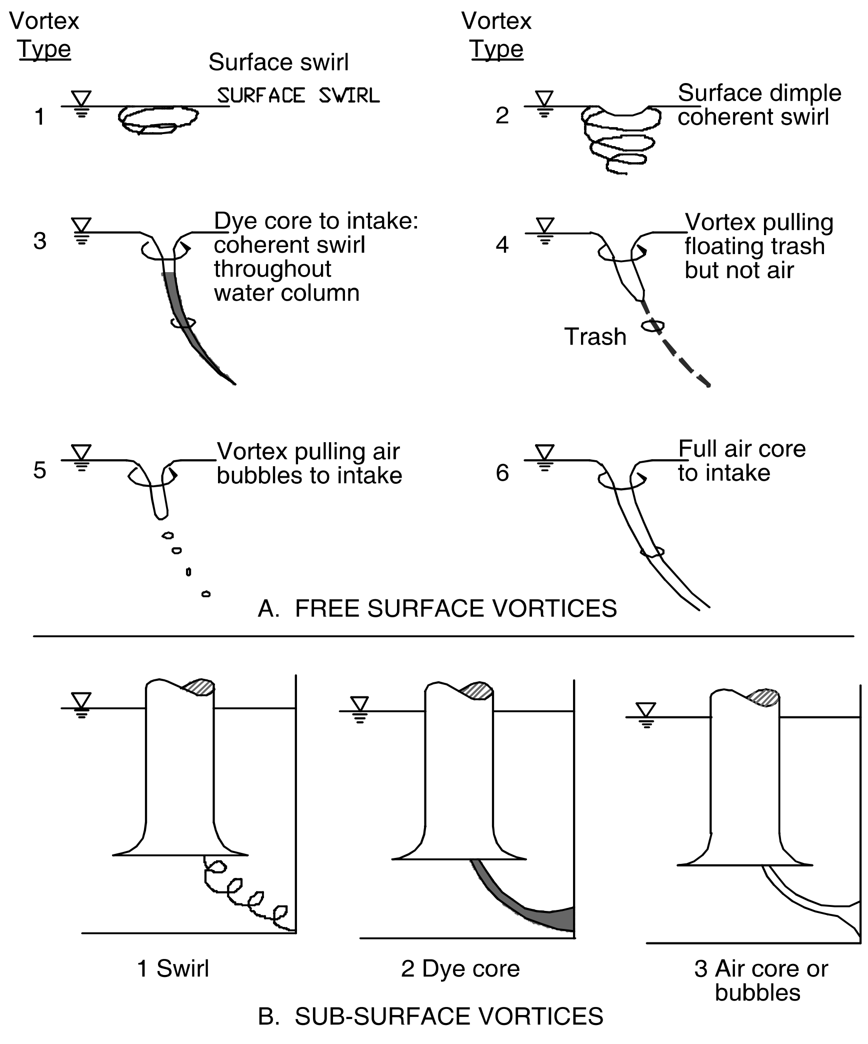


Figure 9.8.23 — Classification of free surface and sub-surface vortices

Sub-surface Vortices: Sub-surface 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 sub-surface vortices, given in Figure 9.8.23B shall be used. The possible existence of sub-surface 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.

Pre-Swirl: 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 pre-swirl 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 9.8.24, located about four suction pipe diameters downstream from the bell or pump suction. The swirl meter shall consist 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.

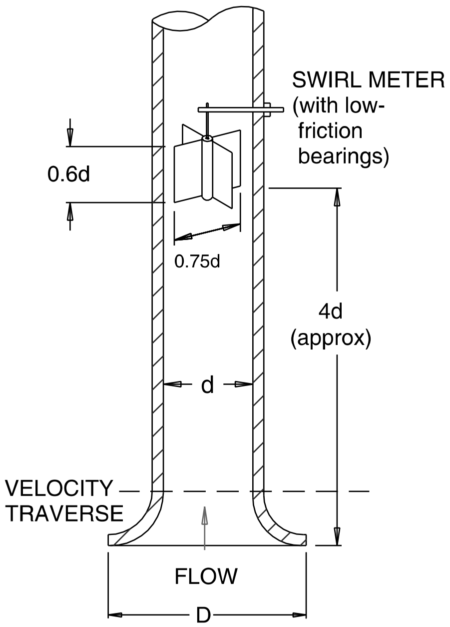


Figure 9.8.24 — Typical swirl meter

$$\theta = \tan^{-1}(\pi dn/u) \tag{9.8.5-6}$$

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 generally 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 Acceptance Criteria below). 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.

Velocity traverses along at least two perpendicular axes at the throat of the model suction bell or at the plane of the pump suction in a piping system shall be obtained for the final design using a pitot-static tube or other suitable instrument capable of determining the axial velocity component with a repeatability of ±2% or better. 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.

9.8.5.6 Acceptance criteria

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

- Free surface and sub-surface vortices entering the pump must be less severe than vortices with coherent (dye) cores (free surface vortices of Type 3 and sub-surface vortices of Type 2 in Figure 9.8.23). 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.

9.8.5.7 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.

9.8.5.8 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.

9.8.6 Inlet bell design diameter (D)

Designing a sump to achieve favorable inflow to the pump or suction pipe bell requires control of various sump dimensions relative to the size of the bell. For example, the clearance from the bell to the sump floor and side walls and the distance to various upstream intake features is controlled in these standards by expressing such distances in multiples of the pump or inlet bell diameter. Such standardization of conditions leading to, and around, the inlet bell reduces the probability that strong submerged vortices or excessive pre-swirl will occur. Also, the required minimum submergence to prevent strong free-surface vortices is related to the inlet bell (or pipe) diameter (see Section 9.8.7).

If the pump or pipe suction inlet diameter D has been selected prior to designing the sump, then the sump design process (see Table 9.8.2) can proceed without using the information provided in this section. However, only the use of inlet sizes within the guidelines provided in this section will produce sump dimensions that comply with these standards. Use of bell or inlet diameters outside the range recommended herein will also comply with these standards if a hydraulic study is conducted in accordance with Section 9.8.5 to confirm acceptable inflow conditions as required by Section 9.8.5.6.

If the pump (or pipe suction inlet) has not been selected, 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 diameter velocities is provided in Figure 9.8.25, 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). Using industry experience and about one standard deviation of the range of inlet bell sizes which may be provided by pump vendors for a given flow 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 (or inlet pipe) 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 Table 9.8.3 and are also shown on Figure 9.8.25 in terms of the recommended bell diameter range for a given flow per pump or inlet. Although the survey indicated that pumps with bells outside this range may be proposed, experience indicates that inlet bell (or inlet pipe) velocities higher than the recommended range are likely to cause hydraulic problems. Use of lower velocities would produce unnecessarily large pump bells (or inlet pipes) and, therefore, sumps.

For sump design prior to pump selection, the recommended inlet bell diameter shown on Figure 9.8.25 shall be used. This recommended bell diameter is based on an inlet velocity of 1.7 m/s (5.5 ft/s). 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 suppressor) shall fall within the acceptable range to produce an inlet velocity within the limits indicated in Table 9.8.3. An inlet bell diameter within this range will produce a sump geometry that complies with these standards on minimum submergence and sump dimensions, without changing the sump design based on the recommended inlet bell diameter.

9.8.7 Required submergence for minimizing surface vortices

9.8.7.1 Introduction

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 hydraulic 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 non-uniform (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 9.8.23.

9.8.7.2 Controlling parameters

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

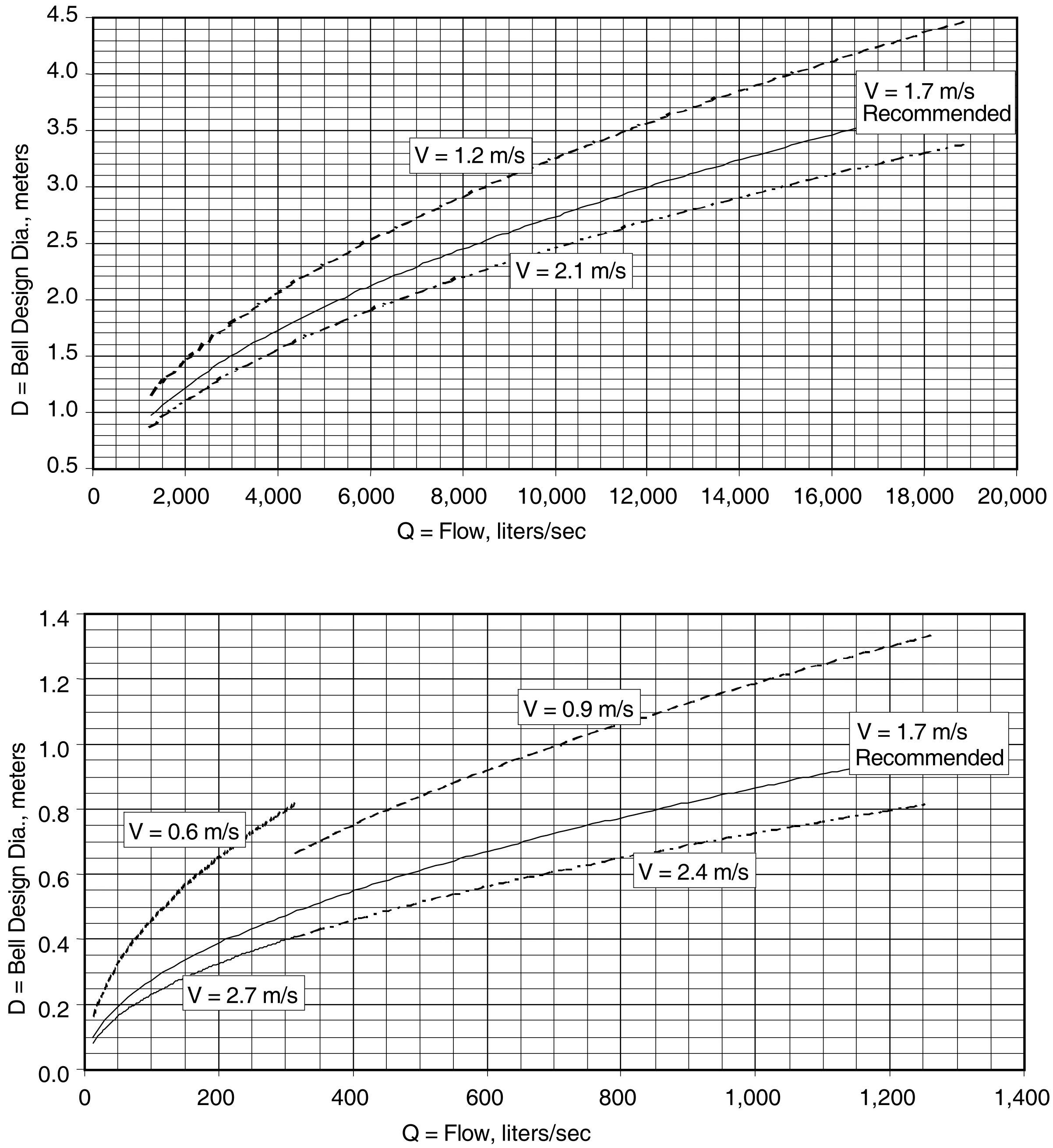
$$VT = f(F_D, N\Gamma, S/D, G)$$

Where:

VT = vortex type (strength and persistence)

f = a function

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



V = Average bell velocity, m/s Q = flow, l/s D = Outside Bell Diameter, m = $[Q/(785V)]^{0.5}$

Figure 9.8.25A — Recommended inlet bell design diameter (OD)

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

S = Submergence

D = Diameter of inlet or bell

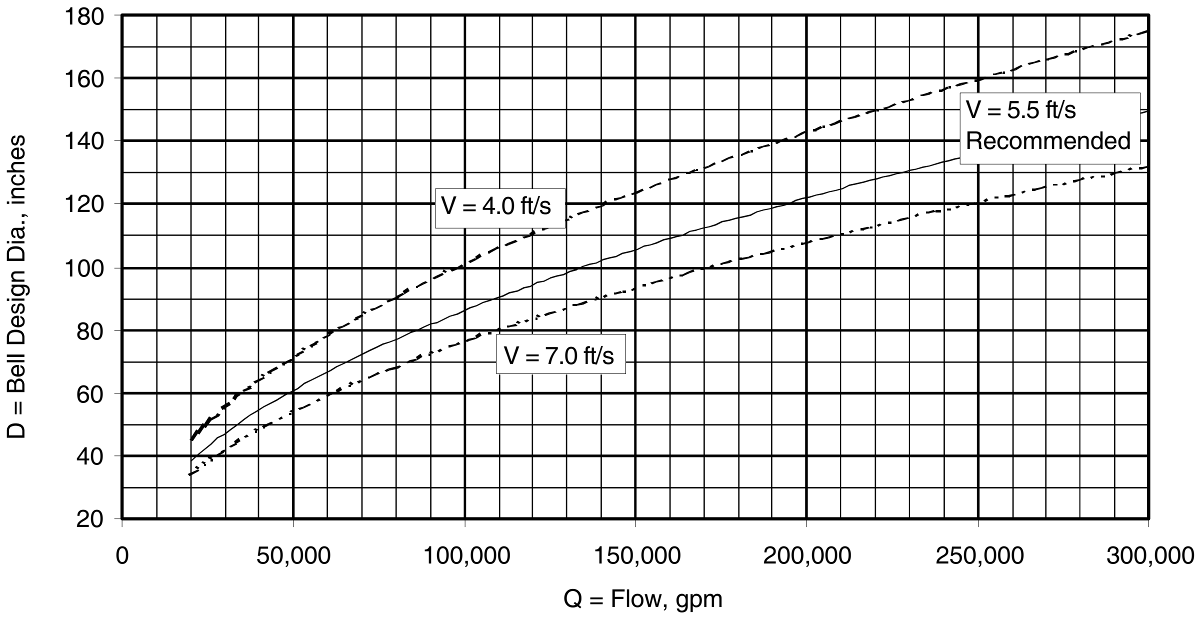
G = Geometry

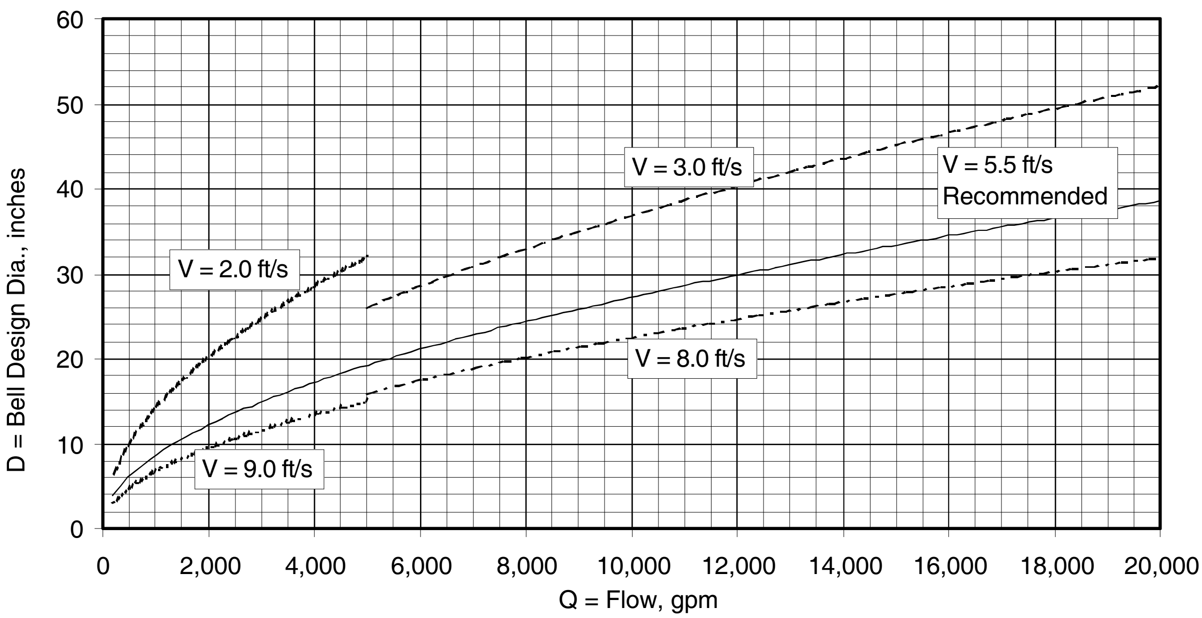
Γ = Circulation ($2\pi r V_t$ for concentric flow about a point with a tangential velocity V_t at radius r)

V = Velocity at inlet (= $4Q/\pi D^2$)

g = Gravitation acceleration

Q = Flow





V = Average bell velocity, ft/s Q = flow, gpm D = Outside Bell Diameter, inches = $(0.409Q/V)^{0.5}$

Figure 9.8.25B — Recommended inlet bell design diameter (OD) (US units)

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

$$VT = f(F_D, S/D)$$

This formula indicates that a plot of S/D vs. F_D would contain a family of curves, each representing different values of vortex strength, VT (refer to Figure 9.8.23A). 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).

$$S/D = 1.0 + 2.3F_D \tag{9.8.7-1}$$

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 non-circular openings, giving the same area as a circular opening)

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

V = Velocity at inlet face = Flow/Area

This equation indicates that 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 9.8.6 allows some variation in the Froude number. Thus, Equation 9.8.7-1 is recommended, rather than a fixed relative submergence.

9.8.7.3 Application considerations

For a given flow, Q, an inlet diameter may be selected in accordance with Section 9.8.6. The recommended minimum submergence for that diameter D would be given by

Metric:

$$S = 1.0D + 2.3[Q/(0.785D^2)/(gD)^{0.5}]D$$

or

$$S = D + Q/D^{1.5}/1069$$

NOTE: S is in meters for g = 9.8 m/sec^2, Q in l/s, and D in meters.

US units:

$$S = 1.0D + 2.3[(12 \times 0.409Q/D^2)/(12gD)^{0.5}]D$$

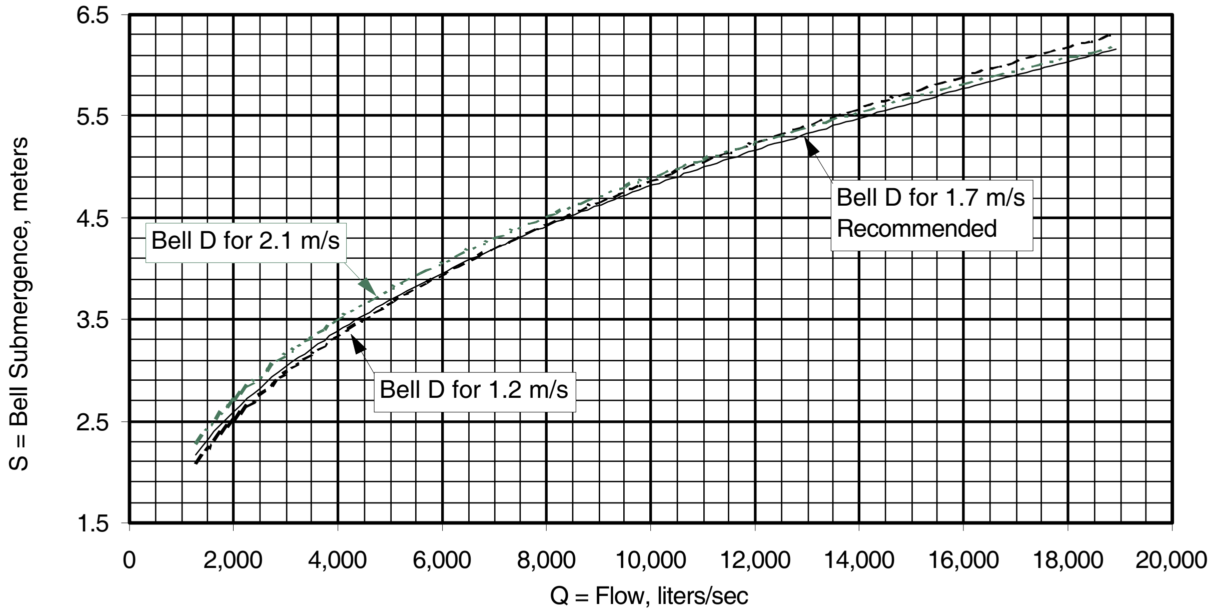
or

$$S = D + 0.574Q/D^{1.5}$$

NOTE: S is in inches for g = 32.2 ft/sec^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 9.8.6, 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 9.8.6, the required minimum submergence for reducing the severity of free-surface vortices is shown on Figure 9.8.26. This figure also shows the recommended minimum submergence for the limits of the bell diameter that comply with these standards, see Figure 9.8.25 and Table 9.8.3. Due to the small change in submergence, no change in submergence from that calculated with the recommended bell



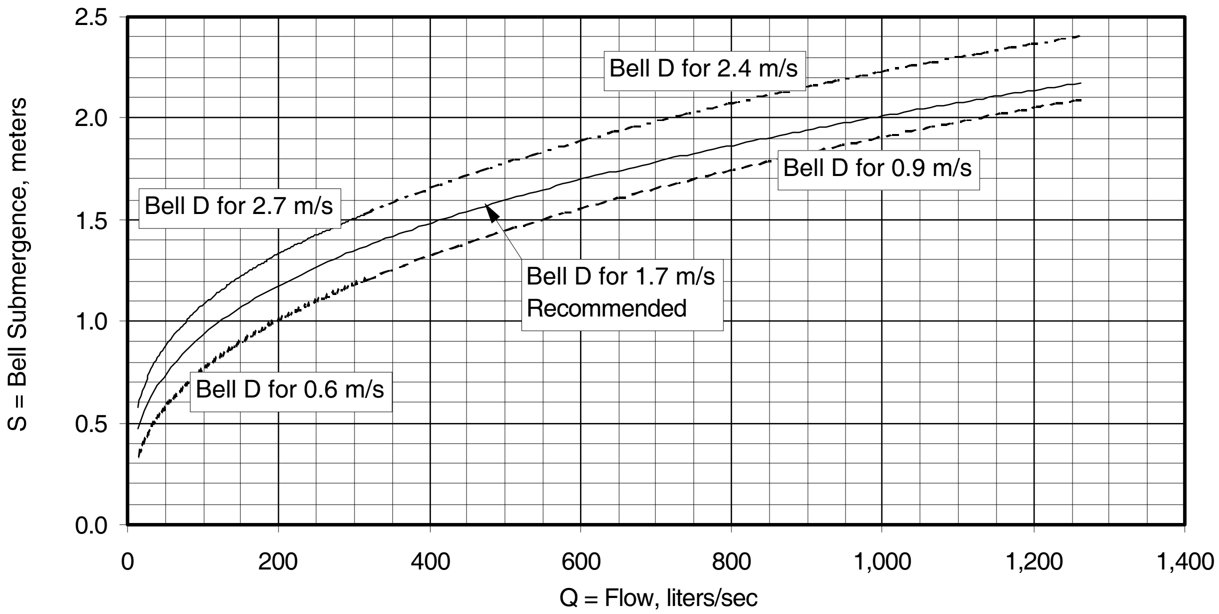
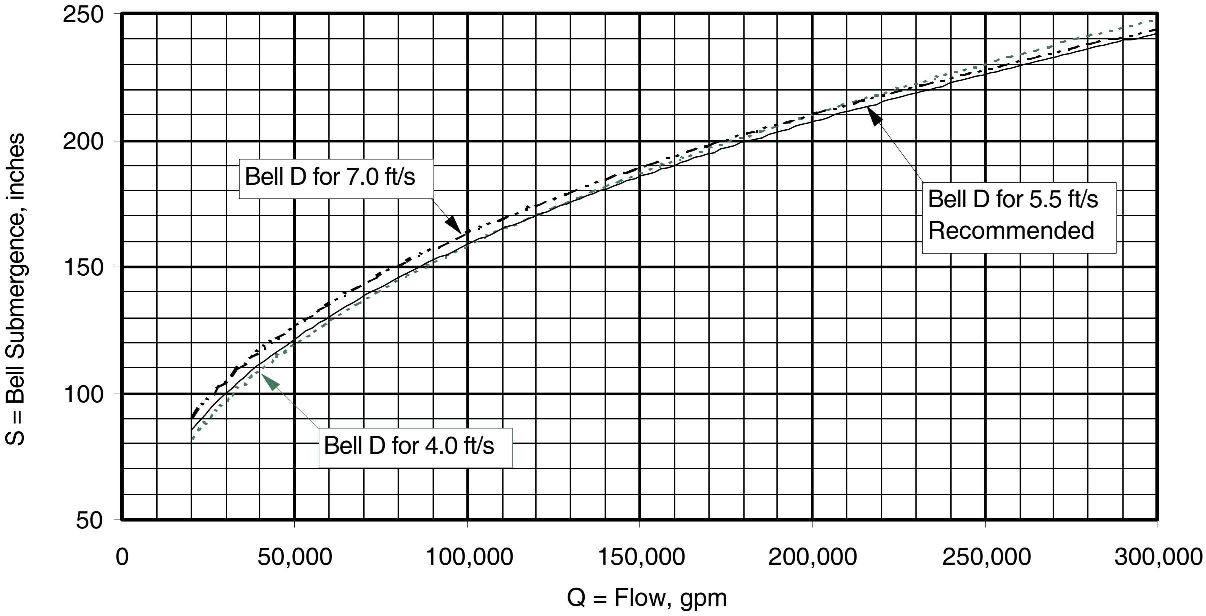


Figure 9.8.26A — Recommended minimum submergence to minimize free surface vortices



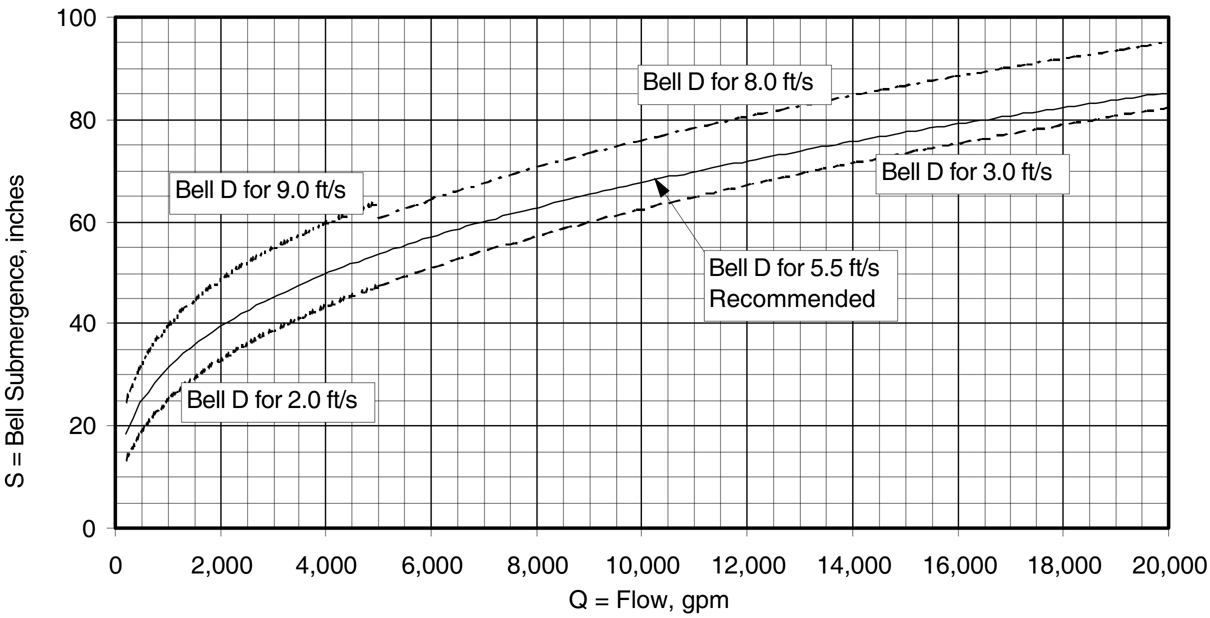


Figure 9.8.26B — Recommended minimum submergence to minimize free surface vortices (US units)

diameter is needed, as long as the final selected bell diameter is within the limits that comply with these standards.

9.8.8 Glossary and nomenclature

9.8.8.1 Glossary

Terms	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 9.8.23.
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 super-critical 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.
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 that are 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 back wall and the sump bottom. It is also referred to as fillets, such as “side wall fillets” and “back wall 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).
Check Valve	Piping component used to prevent reverse flow.
Circular Well	A suction chamber circular in shape in plan.
Cone	See “Floor Cone.”
Critical Depth	The liquid depth which has the minimum specific energy for a given flow, corresponding to a Froude Number equal to one (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 non-wetted environment.
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.

Terms	Definition
Floor Vane	A vertical plate aligned with the approach flow and centered under the suction bell.
Flow Straighter	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 9.8.5-1).
Guide Vanes	Devices used in the suction approach that directs the flow in an optimal manner.
Hydraulic Jump	A turbulent sudden increase in liquid depth as the flow decelerates from super-critical to sub-critical 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.
Mixer	A mechanical device that produces an axial propeller jet, often used for maintaining suspension of solids-bearing liquids in wet wells and tanks.
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.
Piping Reducer	Any change in pipe size, or line area, that results in either an increase or decrease in velocity.
Pre-swirl	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 9.8.5.3).

Terms	Definition
Scale	The ratio between geometric characteristics of the model and prototype.
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.
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	Pressure head plus velocity head referenced to the invert of a conduit.
Specific Speed	Equivalent to a dimensionless number, a high value denotes a high-flow – low-head pump while a low value denotes a low-flow – high-head pump.
Soffit	Inside top of a pipe.
Sequent Depth	The depth of liquid following a hydraulic jump.
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. Refer to Formed Suction Intake.
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 9.8.5-7).
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, generally 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 Figure 9.8.23).
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 side walls of an intake.
Wall Clearance	Dimensional distance between the suction and the nearest vertical surface.

Terms	Definition
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 9.8.5.3).
Wet-Pit Suction	A suction with the pump fully wetted.
Wet Well	A pump intake basin or sump having a confined liquid volume with a free water surface designed to hold liquid in temporary storage to even out variations between inflow and outflow. See Forebay.

9.8.8.2 Nomenclature

Sym.	Definition	Reference Location
A	Distance from the pump inlet centerline to the intake structure entrance	Fig. 9.8.1, Table 9.8.1
A_t	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, Table 9.8.1
B	Distance from the back wall to the pump inlet bell centerline	Fig. 9.8.1, Table 9.8.1, Fig. 9.8.18
C	Distance between the inlet bell and floor	Fig. 9.8.1, Table 9.8.1, Fig. 9.8.18
C_b	Inlet bell or volute clearance for circular pump stations	9.8.2.3.2.1, 9.8.2.3.2.4, Fig. 9.8.4, Fig. 9.8.5
C_f	Floor clearance on circular pump stations	9.8.2.3.2.1, 9.8.2.3.2.2, Fig. 9.8.4, Fig. 9.8.5
C_w	Wall clearance on circular pump stations	9.8.2.3.2.1, 9.8.2.3.2.3, Fig. 9.8.4, Fig. 9.8.5
D	Inlet bell diameter or inlet bell design diameter	Foreword, 9.8.2.1.3, 9.8.2.1.4, Eq. 9.8.2.1-1, Eq. 9.8.2.1-2, Fig. 9.8.1, Fig. 9.8.2, Table 9.8.1, Table 9.8.2, 9.8.2.3.2.2, 9.8.2.3.2.3, 9.8.2.4.7, 9.8.2.4.8, 9.8.2.4.9, Fig. 9.8.6, Fig. 9.8.11, 9.8.2.7.2, 9.8.2.7.4, 9.8.3.2.3.1, 9.8.3.2.3.2, Fig. 9.8.13, Fig. 9.8.14, 9.8.3.3.3, Fig. 9.8.17, 9.8.3.4.4.1, Fig. 9.8.18, 9.8.5.3, 9.8.6, Table 9.8.3, Fig. 9.8.25, 9.8.7.2, Eq. 9.8.7-1, Fig. 9.8.26, Fig. A.10, Fig. A.11
D	Diameter of circle with area equivalent to rectangular area at FSI entrance	9.8.2.2.3
D	Tank outlet fitting diameter	9.8.2.5.4, Fig. 9.8.9, 9.8.2.5.5
D	Turning vane inlet diameter	9.8.2.6.4, Fig. 9.8.10
D	Pipe diameter	Fig. 9.8.19
D_1	Vertical can riser diameter	Fig. 9.8.10
D_1	Can inside diameter	Fig. 9.8.11, Fig. 9.8.12
D_1	Diameter of suction header	Fig. 9.8.22
D_2	Diameter of suction header take-off pipe	Fig. 9.8.22
D_b	Inlet bell or volute diameter	9.8.2.3.2.1, 9.8.2.3.2.6, Fig. 9.8.4, Fig. 9.8.5
D_M	Well motor cooling shroud diameter	Fig. 9.8.12

Sym.	Definition	Reference Location
D_p	Inside diameter of approach pipe	C-2, C-3, Table C.1, Table C.2
D_s	Sump diameter	9.8.2.3.2.1, 9.8.2.3.2.5, Fig. 9.8.4, Fig. 9.8.5
D_T	Theoretical diameter	9.8.2.6.6
d	Diameter at outlet of formed suction intake	Fig. 9.8.3, Type 10 formed suction intake
d	Diameter of the pipe at the swirl meter	Eq. 9.8.5-7, Fig. 9.8.24
EGL	Energy grade line	C-3
F	Froude number	9.8.5.3, Eq. 9.8.5-1
F_D	Froude number	Foreword, Fig. 9.8.1, Eq. 9.8.2.1-1, Eq. 9.8.2.1-2, Table 9.8.1, 9.8.2.1.4, 9.8.2.2.3, 9.8.2.5.4, 9.8.2.7.4, Fig. 9.8.13, Eq. 9.8.7-1, 9.8.7.2
F_r	Froude number ratio, F_m/F_p	9.8.5.3, Eq. 9.8.5-2
F_m	Froude number of model	9.8.5.3, Eq. 9.8.5-2
F_p	Froude number of prototype	9.8.5.3, Eq. 9.8.5-2
G	Geometry	9.8.7.2
g	Acceleration of gravity	9.8.2.1.4, Eq. 9.8.2.1-1, 9.8.2.5.4, 9.8.5.3, Eq. 9.8.5-1, 9.8.7.2, 9.8.7.3
H	Minimum liquid depth	Fig. 9.8.1, Fig. 9.8.2, Table 9.8.1, Fig. 9.8.18
H_f	Height of FSI	Fig. 9.8.3, 9.8.2.2.3, Fig. 9.8.7
h	Minimum height of constricted bay section near the pump	Fig. 9.8.2, Table 9.8.1
L	Width of rectangular entrance for intake suction piping	Fig. 9.8.18
L	A characteristic length (usually bell diameter or submergence)	9.8.5.3, Eq. 9.8.5-1
L_1	Distance between suction piping take-offs	Fig. 9.8.22
L_2	Distance from suction header or flow disturbing device to pump flange	Fig. 9.8.22
L_r	Geometric scale of model	Eq. 9.8.5-3, Eq. 9.8.5-4, Eq. 9.8.5-5
L_v	Characteristic length of a cubic cage type vortex suppressor	A-6, Fig. A.12
N_Γ	Circulation number	9.8.7.2
n	Revolutions/second of the swirl meter	Eq. 9.8.5-6
n	Manning's n	C-2.2, Tables C.1 and C.2
OD	Outside diameter of pump bell or inlet bell	Table 9.8.3
Q	Flow	9.8.2.6.6, Table 9.8.3, Fig. 9.8.25, 9.8.7.2, 9.8.7.3, Fig. 9.8.26, B-2, Eq. B-1
Q_m	Flow scale in model	Eq. 9.8.5-4
Q_p	Flow scale in prototype	Eq. 9.8.5-4
Q_r	Flow scale ratio, model/prototype	Eq. 9.8.5-4
Q_{in}	Inflow into sump or pump station	B-2, Eq. B-1, Eq. B-2, Eq. B-3
Q_{p1}	Flow rate for pump no. 1 or flow with one pump running	B-2, Eq. B-2, Fig. B.2, B-3

Sym.	Definition	Reference Location
Q_{p2}	Flow with two pumps running	Fig. B.2, B-3
R	Reynolds number	9.8.5.3
r	Radius of curvature	Fig. 9.8.3, 9.8.3.2.3, Fig. 9.8.13
r	Radius of tangential velocity component	9.8.7.2
S	Minimum submergence depth	Foreword, Fig. 9.8.1, Eq. 9.8.2.1-2, 9.8.2.1.4, Table 9.8.1, 9.8.2.2.3, Fig. 9.8.3, 9.8.2.3.2.1, Fig. 9.8.4, Fig. 9.8.5, Fig. 9.8.6, Fig. 9.8.7, 9.8.2.5.4, Fig. 9.8.8, Fig. 9.8.12, 9.8.2.7.4, Fig. 9.8.13, Fig. 9.8.17, Fig. 9.8.18, 9.8.7.3, 9.8.7.2, 9.8.5, Eq. 9.8.7-1, Fig. 9.8.26
T	Pump cycle time in minutes	B-2, Eq. B-1, Eq. B-2, B-3
T_m	Time scale of model	Eq. 9.8.5-5
T_p	Time scale of prototype	Eq. 9.8.5-5
T_r	Time scale ratio, model/prototype	Eq. 9.8.5-5
u	Average axial velocity (such as in the suction bell)	9.8.5.3, Eq. 9.8.5-1
u	Average axial velocity at the swirl meter	Eq. 9.8.5-6
V	Velocity	Eq. 9.8.2.1-1, 9.8.2.1.4, 9.8.2.2.3, 9.8.2.5.4, 9.8.2.5.5, Fig. 9.8.9, Fig. 9.8.10, 9.8.2.7.4, 9.8.6, Table 9.8.3, Fig. 9.8.25, 9.8.7.2
Vol	Effective sump volume	B-2, Eq. B-1
Vol_1	Active sump volume for pump no. 1	B-2, Eq. B-2, B-3
Vol_2	Active sump volume for pump no. 2	B-3
Vol_{TOT}	Total active volume of sump	B-3
V_c	Cross-flow velocity	Fig. 9.8.1, Table 9.8.1
V_m	Velocity scale in model	Eq. 9.8.5-3
V_p	Velocity scale in prototype	Eq. 9.8.5-3
V_r	Velocity scale ratio, model/prototype	Eq. 9.8.5-3, Eq. 9.8.5-4, Eq. 9.8.5-5
v_t	Tangential velocity	9.8.7.2
V_x	Pump bay velocity	Fig. 9.8.1, Table 9.8.1
VT	Vortex type	9.8.7.2
W_e	Weber number	9.8.5.3
W	Pump bay entrance width	Fig. 9.8.1, Table 9.8.1, Fig. 9.8.2, Fig. 9.8.18
W	Width of FSI	9.8.2.2.3, Fig. 9.8.3, Fig. 9.8.7
w	Constricted bay width near the pump	Fig. 9.8.2, Table 9.8.1
X	Pump bay length	Fig. 9.8.1, Table 9.8.1
Y	Distance from pump inlet bell centerline to traveling screen	9.8.2.1.4, Fig. 9.8.1, Table 9.8.1
y	Depth	Table C.1, Table C.2
Z_1	Distance from pump inlet bell centerline to diverging walls	Fig. 9.8.1, Table 9.8.1
Z_2	Distance from pump inlet bell centerline to sloping floor	Fig. 9.8.1, Table 9.8.1

Sym.	Definition	Reference Location
α	Angle of floor slope	Fig. 9.8.1, Table 9.8.1
β	Angle of wall divergence	9.8.2.1.4, Fig. 9.8.1,Table 9.8.1
ε	Angle of side wall of trench	Fig. 9.8.13
f	A function	9.8.7.2
ρ	Liquid density	9.8.5.3
Γ	Circulation of the flow	9.8.5.3, 9.8.7.2
ν	Kinematic viscosity of the liquid	9.8.5.3
θ	Swirl angle	Eq. 9.8.5-6
σ	Surface tension of liquid/air interface	9.8.5.3
ϕ	Angle of divergence from constricted area to bay walls	Fig. 9.8.2, Table 9.8.1

Appendix A

Remedial Measures for Problem Intakes

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

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 hydraulic model test is needed to verify whether 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, since 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 generally 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 cross-currents 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 upon 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 hydraulic model study) for analyzing departures from the ideal condition are given in Section 9.8.5.

A-2.1 Open vs. 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 Section 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 cross-currents and non-uniform approach flow patterns. Even if approach flow at the entrance to the structure is uniform, open sumps result in non-uniform

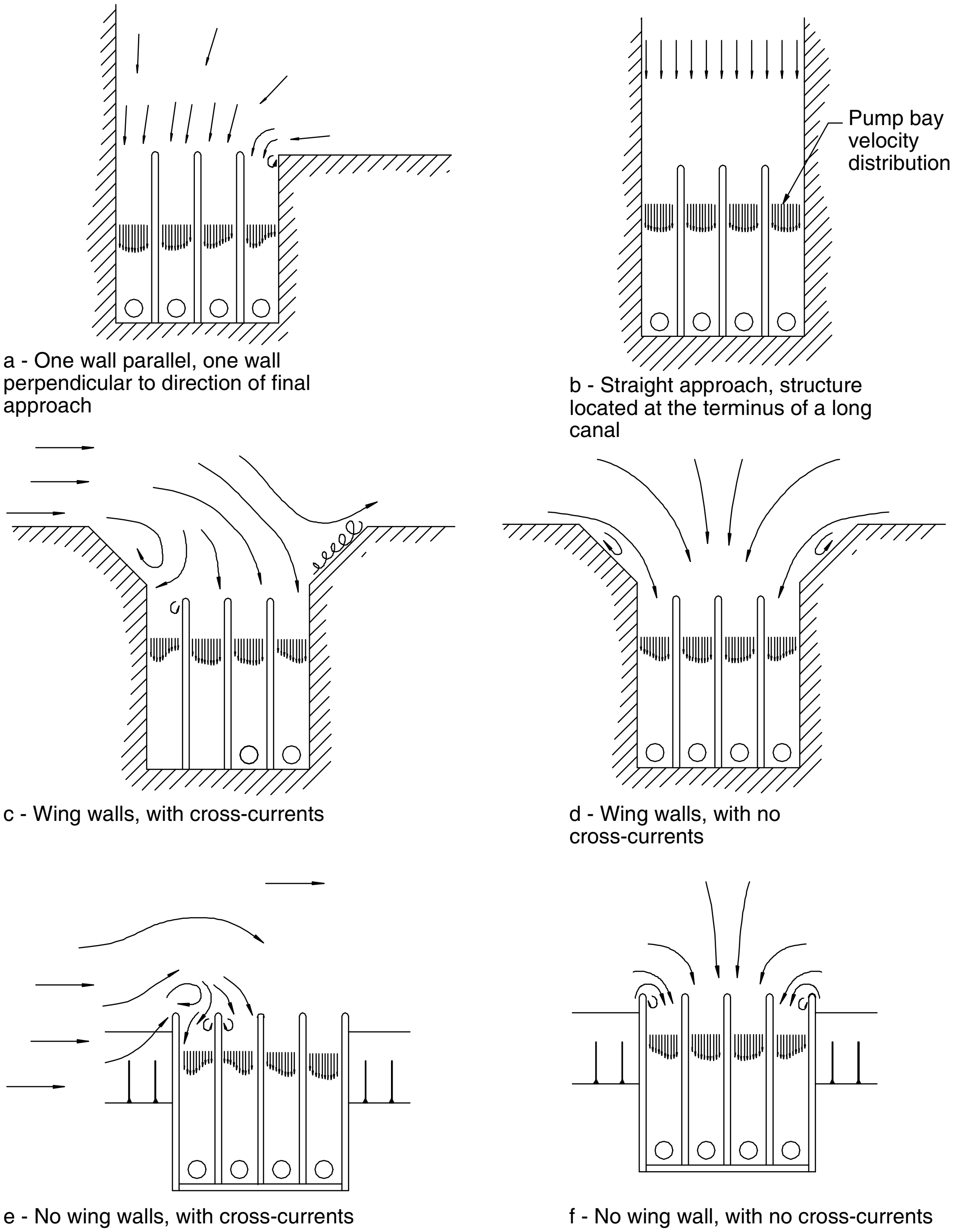


Figure A.1 — Examples of approach flow conditions at intake structures and the resulting effect on velocity, all pumps operating

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 non-uniformly, with a separation area near the right side-wall. 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 b, the dashed line at the wing walls shows a rounded entrance configuration that minimizes flow separation near the entrance to the outer pump bays.

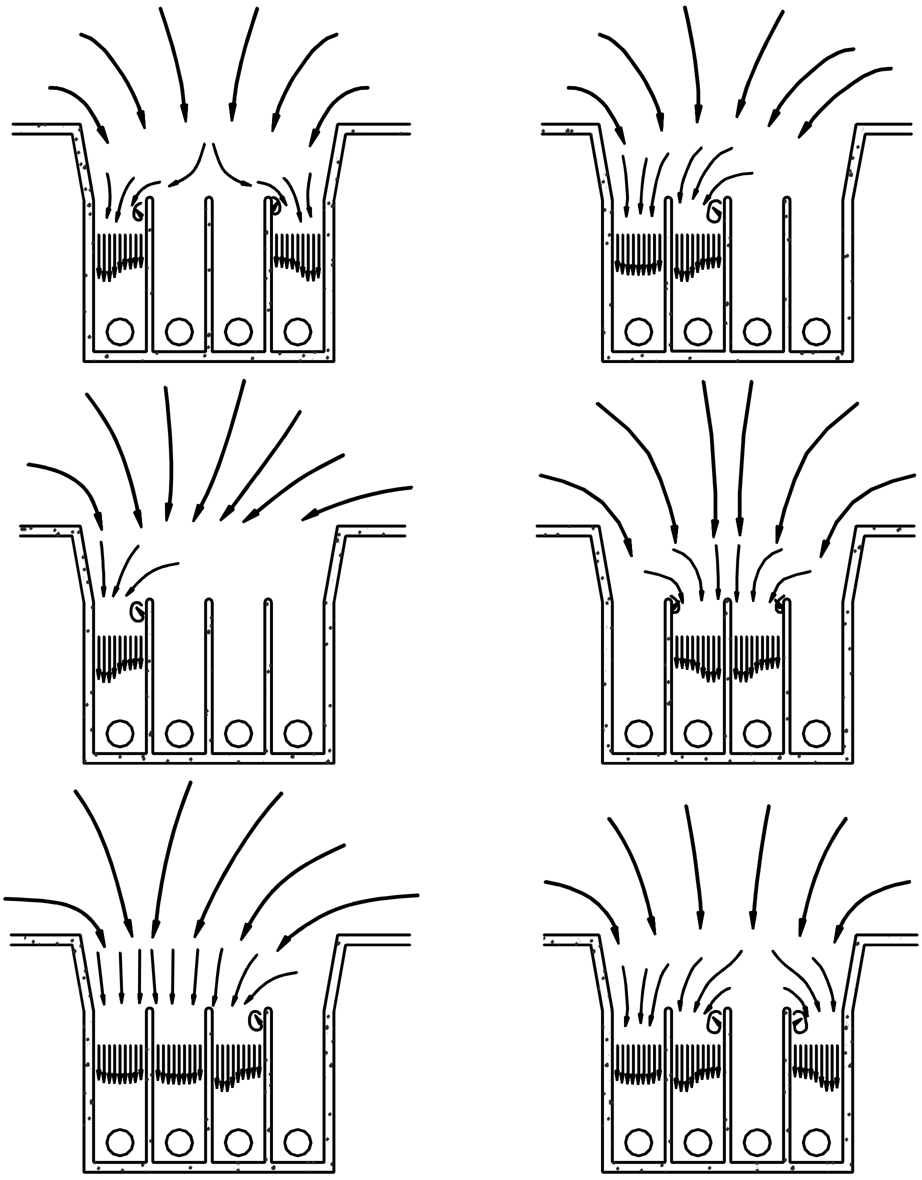


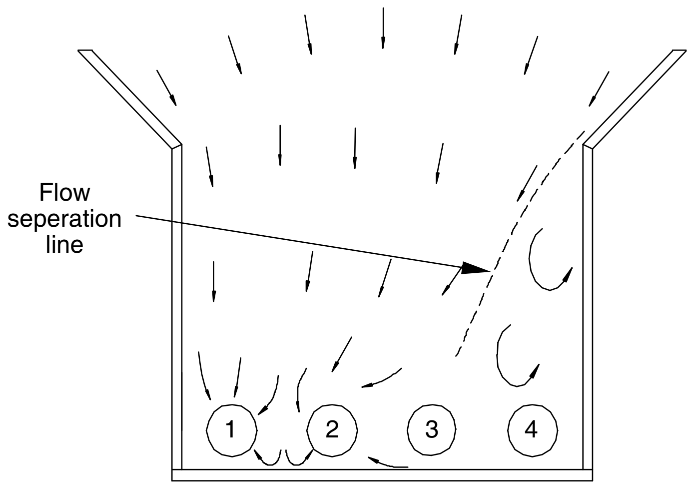
Figure A.2 — Examples of pump approach flow patterns for various combinations of operating pumps

In open sumps (Figure A.3, example a), 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 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 pre-swirl.

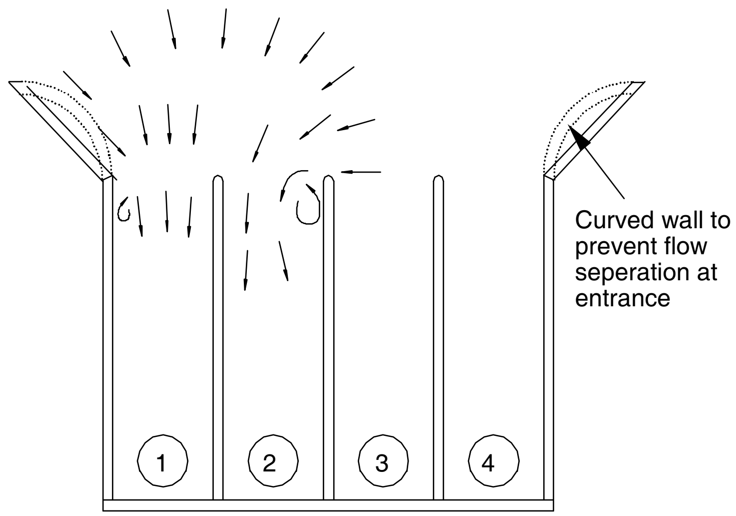
If all four pumps in the open sump were to operate simultaneously, approach flow would be reasonably uniform, but other adverse phenomena could be present. For example, when two adjacent pumps are operating simultaneously, submerged vortices frequently form, connecting both pumps.

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



a - Open sump, Pumps 1 & 2 operating illustrating problem flow patterns



b - 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

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.

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 side walls approaching the pump bays must gradually diverge, and flow baffles of varying geometry may be used to spread the flow at a divergence angle greater than otherwise possible. Figure A.6 shows possible corrective measures.

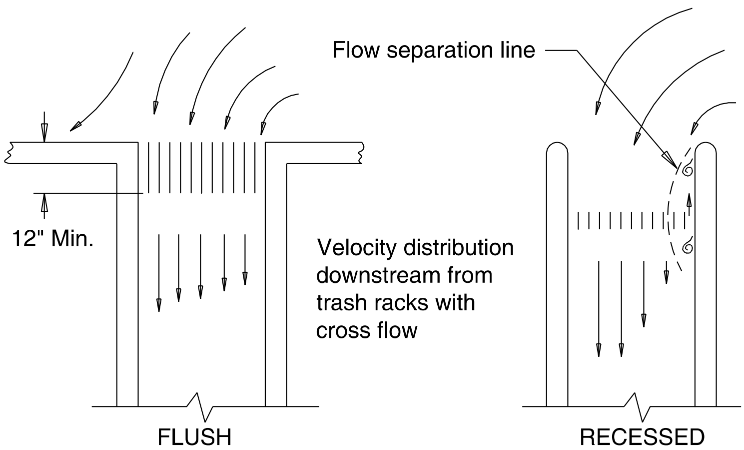


Figure A.4 — Effect of trash rack design and location on velocity distribution entering pump bay

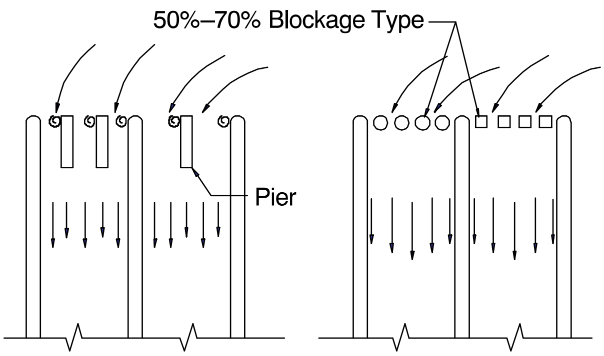


Figure A.5 — Flow-guiding devices at entrance to individual pump bays

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), the jet exiting the center of these screens will attach to one wall or the other, and will result in highly non-uniform flow for an indefinite distance down the channel. The non-uniform flow creates excessive swirl at the pump. The screen exit must be placed a minimum distance of six bell diameters, 6D (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

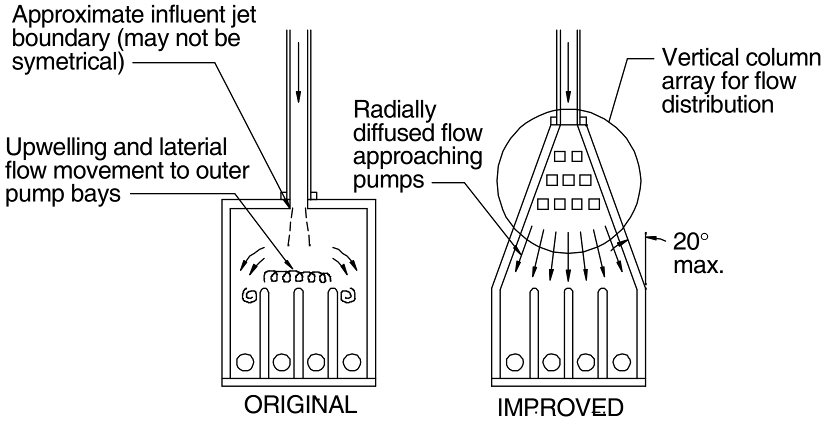
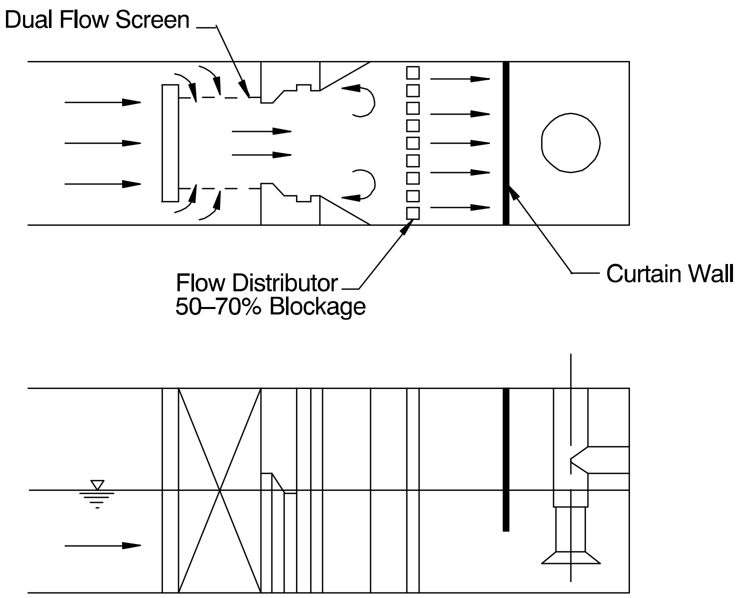


Figure A.6 — Concentrated influent configuration, with and without flow distribution devices



NOTE: Physical hydraulic model study required.

Figure A.7 — Baffling to improve flow pattern downstream from dual flow screen

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 side walls and flow distribution baffles, is shown in Figure A.7.

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

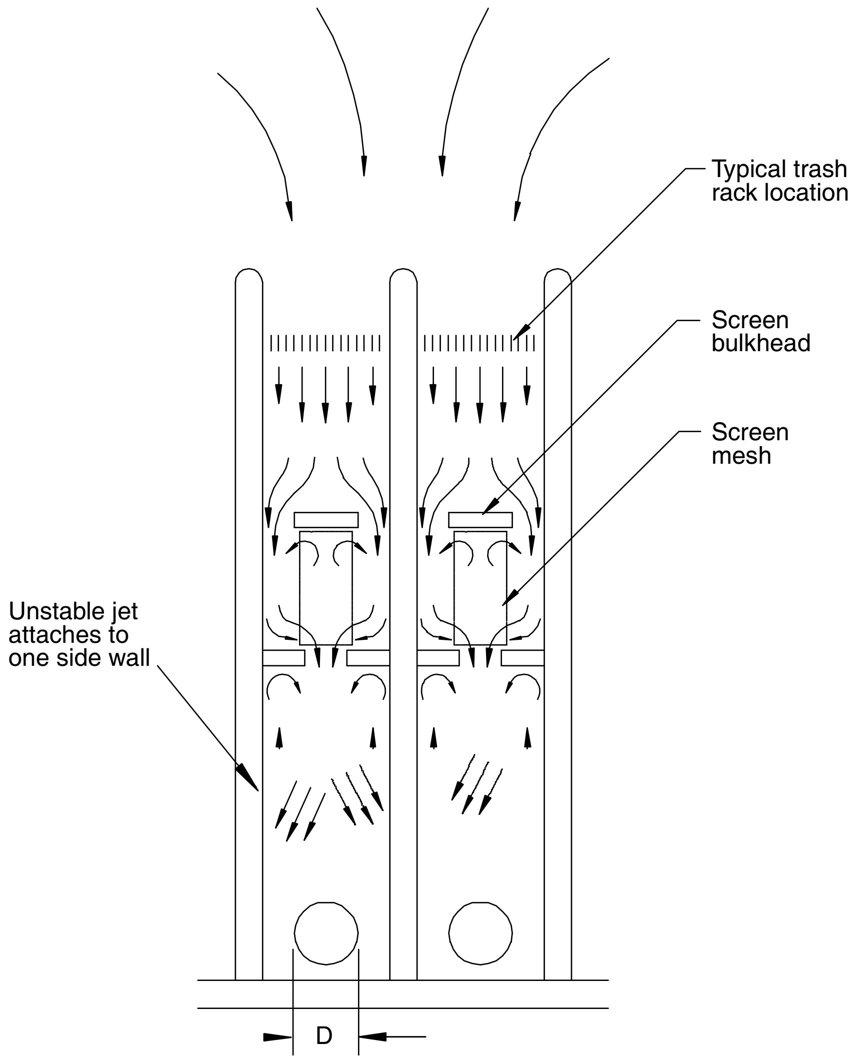
Increasing the number of inflow lines together with a flow distributor across the sump and/or each bay may provide an adequate distribution to the pump bays, see Figure A.9.

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,



NOTE: Physical hydraulic model study required.

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

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 pump manufacturers offer optional “suction umbrellas” to reduce free surface vortices. Usually, suction umbrellas are horizontally oriented flat rings or “washers” attached to the pump bell to increase the bell diameter and reduce velocities at the revised inlet.

Curtain walls, such as shown in Figure A.10, 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.

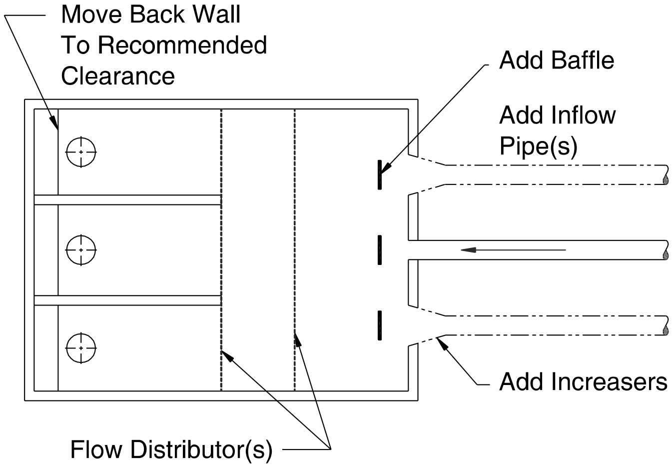


Figure A.9 — Improvements to approach flow without diverging sump walls

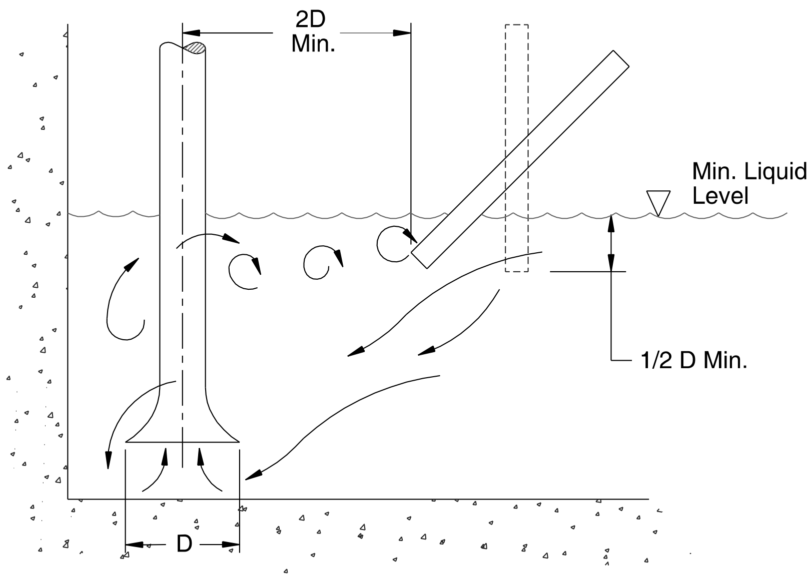


Figure A.10 — Elevation view of a curtain wall for minimizing surface vortices

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 inches) 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 inches). As a temporary measure, floating rafts of various types may be used to suppress surface vortices.

A-5.2 Sub-surface 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 sub-surface 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 Pre-swirl

Whether pre-swirl 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 central splitter and potentially produces a submerged vortex emanating from the flow separation at the central splitter. A cone on the floor would not cause such a submerged vortex problem, but the cone would also not help to control residual pre-swirl.

The most effective way of reducing pre-swirl 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 back wall, 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 (weir) wall across the bay width, close to the upstream side of the pump. This wall, if a few pump 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 pre-swirl and other undesirable hydraulic phenomena.

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 pre-swirl 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 anti-vortex 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 Tanks — suction inlets

Undesirable flow conditions may be created at the pump inlet in the tank depending on the inflow–outflow arrangement in a storage tank, whether the tank inflow is operating while the pump suction (inlet) is operating, and whether there are flow obstructions in the tank. Even if only the pump inlet is operating and there are no flow obstructions in the tank, the non-uniform approach flow to the pump inlet may cause pre-swirl and vortices.

Since a dry-pit pump is usually located some distance downstream from its piping inlet in the tank, the effect of these flow disturbances on the pump is not as severe as with wet-pit pumps. For example, local flow separation, swirl, or velocity non-uniformities, although creating greater head losses at the inlet, may be dissipated in the approach piping to the pump. The main problem is usually entrainment of air (or other tank gases) due to free-surface vortices, 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 inlets to pumps allows the tank to be drawn to lower levels than would otherwise be possible. This benefit requires the use of various anti-vortex devices

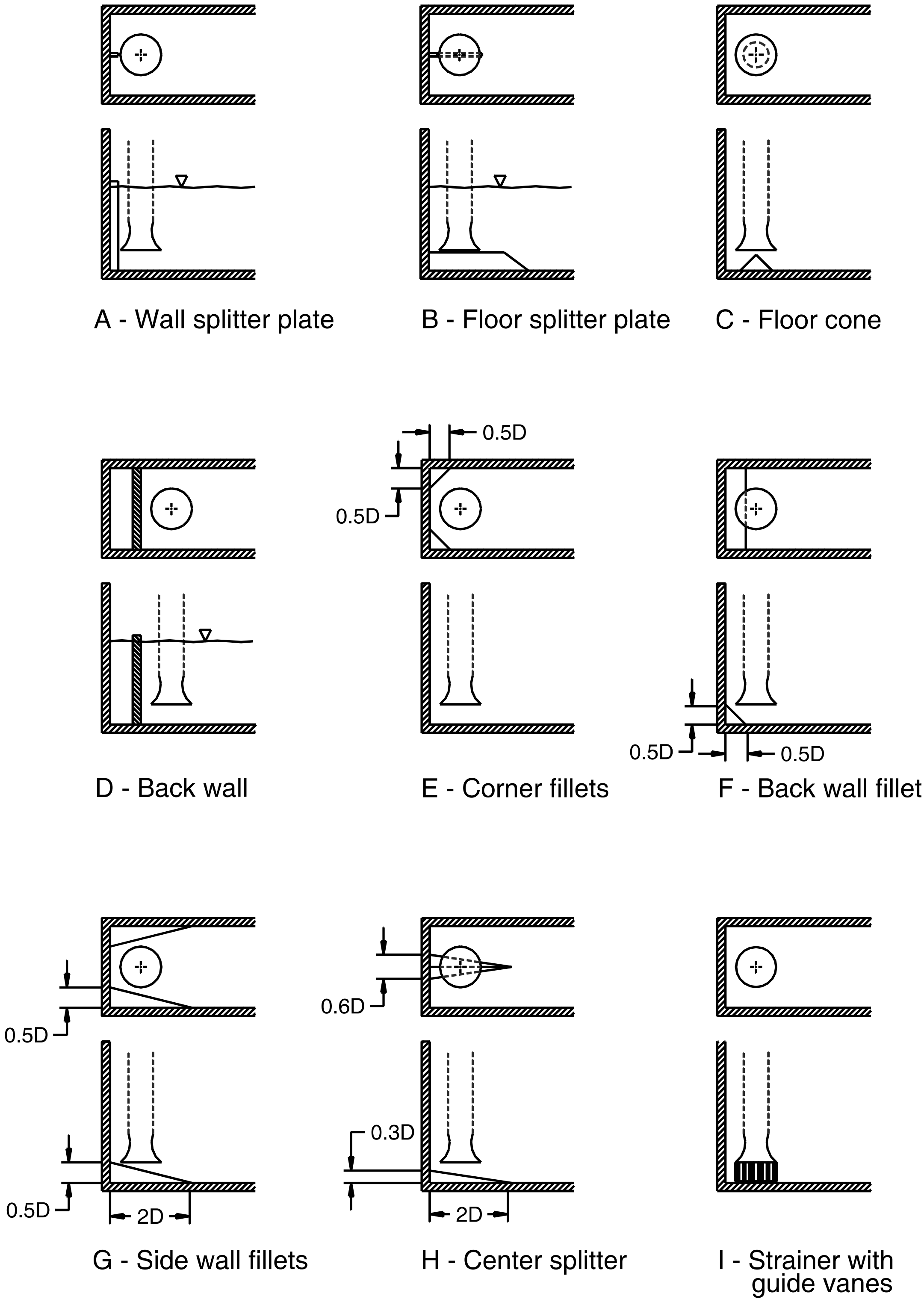


Figure A.11 — Methods to reduce sub-surface vortices (examples A–I)

at the inlet. Some common types of such devices are shown in Figure A.12.

As an alternative, a cage type vortex suppressor may be used, as illustrated in Figure A.12, example 6. The cubic cage may be made of standard 38 mm (1.5 inches) 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 3 inlet pipe diameters, and the top of the cage should be submerged about 150 mm (6 inches) below the minimum liquid level. Non-cubic cage shapes are also effective if the upper (horizontal) grating is at least 3 inlet pipe diameters on each side and is also submerged 150 mm (6 inches) 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

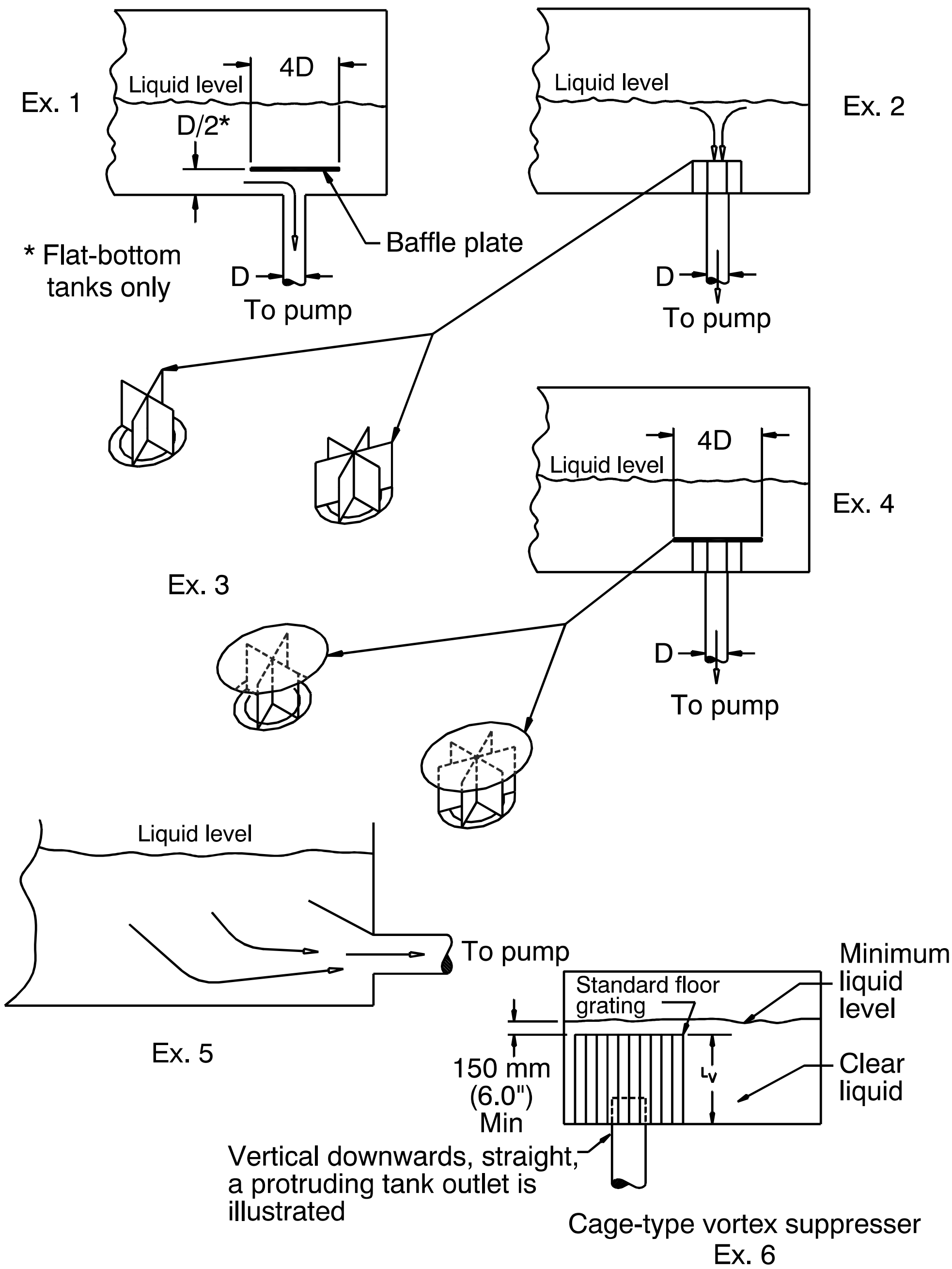


Figure A.12 — Anti-vortex devices

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 inches) submergence above the top of the cage.

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 certain pump controls) except for a requirement that the sump volume must be large enough to keep currents sufficiently low.

B-2 General

Most pumping systems that transfer liquids (as opposed to circulating systems) utilize some form of a pump sump. A pump sump acts as an intermediate buffer zone capable of absorbing inflow fluctuations relative to pumping capacity. The pump sump is often used for intermediate storage to allow constant speed pumps to work in an on/off mode while the pump sump is being filled and emptied. This operation allows for the most efficient use of constant speed pumps. A pump sump should also act to distribute the inflow to the various pumps in a pumping station in such a way that good hydraulic inflow conditions exist at each pump during various operating conditions.

In new construction as well as in upgrading existing pump stations, it is important to know the required active sump volume. This volume is defined by the highest start level and lowest stop level in the pump sump. The minimum required sump volume can be calculated and it depends on the inflow to the pump station, the pump capacities, their allowed cycle time (number of starts per hour allowed for pump, drive, starters, etc., as applicable), and their operating sequence. The limiting parameter is the cycle time. The volume has to be sufficiently large not to exceed the number of starts per hour specified by the motor/pump manufacturer. For the simplest case (one pump operated at constant speed), the maximum number of starts per hour occurs when the inflow is 50% of the pump capacity. For multiple pumps, the operating sequence also affects the volume required. The number of starts per hour a pump and motor system can sustain is determined by the selection of starting equipment, load and inertia characteristics of the pump, and the motor design. With increasing numbers of allowable starts per hour, the requirement for active sump volume is reduced. Alternating the starting pump in multiple pump installations also greatly reduces the required active sump volume.

For pumping systems dealing with solids-bearing liquids, allowing the pump sump level to fluctuate will create differences in flow patterns that may minimize solids sedimentation and particle build-up on the intake surfaces.

There are several methods to calculate the required active sump volume. The sequence with which the pumps are brought on and off line plays an important role as does the total number of pumps. An active sump volume that is too small reduces motor, pump, and electrical equipment life by excessive starting and stopping. A pump station with a sump volume that is too large is expensive to build, and the larger volume may increase the risk of undesirable hydraulic patterns due to stagnant zones and zones of low liquid velocity. For domestic sewage, the increased storage time promotes septicity during periods of low flow. Since an increase in the active volume often is accomplished by constructing a deeper station, a larger volume leads to higher pumping head and consequently a higher energy usage. In a situation where contaminated or solids-bearing liquid is pumped, a larger pump sump would also be more difficult to maintain in a clean state.

To calculate the minimum sump volume for an application with constant speed pumps, start with the following relationship:

$$T = \left(\frac{Vol}{Q_{in}} + \frac{Vol}{Q - Q_{in}}\right) \qquad \text{(B.1)}$$

Where:

T = The pump cycle time in minutes, i.e., the time between two consecutive starts (time to fill and empty).

Vol = The effective sump volume, i.e., the volume between the start level and the stop level in liters (cubic feet).

Q_{in} = The inflow into the pump station in l/min (cubic feet per minute).

Q = The pump flow rate in l/min (cubic feet per minute).

Differentiating the equation shows that the maximum number of starts per hour occurs at an inflow rate which is half of the pumping rate.

Rearranging Equation B.1 and solving for Vol_1:

$$Vol_1 = T\left(\frac{Q_{in}}{Q_{p1}}\right)(Q_{p1} - Q_{in}) \quad \text{(B.2)}$$

Where:

Vol_1 = The active sump volume for pump 1 in liters (cubic feet).

T = Pump cycle time (time to fill and empty) in minutes.

Q_{in} = The inflow into the station in l/min (cubic feet per minute).

Q_{P1} = The flow rate of pump 1 in l/min (cubic feet per minute).

Two operational sequences for multi-pump stations are:

Sequence 1 The pumps start and stop at individual levels; as the level rises in the sump, each pump is sequentially brought on-line until the inflow is surpassed. As the level falls, each pump is brought off line in reverse order (see Figure B.1).

Sequence 2 The pumps start as in sequence 1, but all pumps continue to operate to the minimum stop level (see Figure B.1).

The staggered stop levels in sequence 1 results in a lower energy consumption, but may require a larger active sump volume.

B-3 Minimum sump volume sequence

The required active sump volume and cycle time in relation to pump capacity can be calculated by using Equation B.1 in combination with the corresponding pump and system head curves.

When the second pump is brought on line, the flow rate in the system increases, thus producing increased losses. This scenario effectively reduces the capacity of each pump running (see Figure B.2).

Each volume must be calculated with the appropriate pump capacity.

Example B-1-A (A station with two duty plus one standby pump) has three constant speed pumps, each with a capacity of 150 l/s (2400 gpm) at 15 m (50 ft), which is the first duty point on the system curve. The second duty point is 250 l/s (4000 gpm) at 16.7 m (55 ft) (two pumps together). What is the minimum sump volume using sequence 1 operation and 10 starts per hour?

Convert the pump flow rates to l/min (cfm), by multiplying with 60 (7.48 gallons per cubic foot).

150 l/s = 9000 l/min (2400 gpm = 320 cfm)

250 l/s = 15,000 l/min (4000 gpm = 535 cfm)

The highest pump cycling frequency occurs when the inflow equals 50% of the pump flow with one pump running, therefore the Vol_1 is determined for $Q_{in} = 5$ l/s (159 cfm).

Pump Cycle Time 1 in Metric Units:

$$T = \frac{60 \times 60}{10} = 360 \text{ seconds}$$

$$Vol_1 = T\left(\frac{Q_{in}}{Q_{p1}}\right)(Q_{p1} - Q_{in})$$

$$Vol_1 = 360\left(\frac{75}{150}\right)(150 - 75)$$

$$Vol_1 = 13{,}500 \text{ liters}$$

Vol_2 is calculated with the following equation. An iteration or trial and error show that the shortest cycle time occurs for $Q_{in} = 200$ l/s (424 cfm).

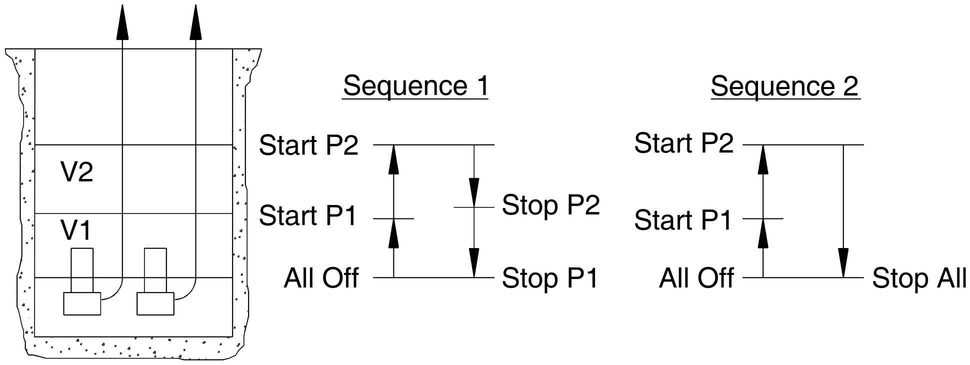


Figure B.1 — Operational sequences

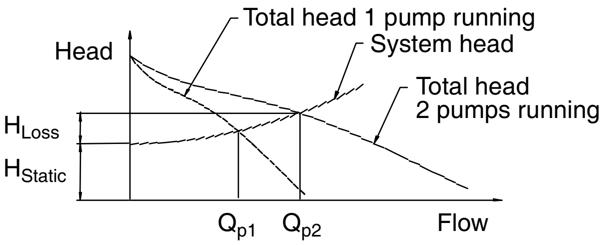


Figure B.2 — Pump and system head curves

$$Vol_2 = T(Q_{in} - Q_{p1})\frac{(Q_{p2} - Q_{in})}{(Q_{p2} - Q_{p1})}$$

$$Vol_2 = 360(200 - 150)\frac{(250 - 200)}{(250 - 320)}$$

$$Vol_2 = 9000 \text{ liters}$$

Where:

Q_{P2} = the flow with two pumps running

Thus, the minimum sump volume is:

$$Vol_{tot} = Vol_1 + Vol_2 = 22{,}500 \text{ liters}$$

for this example.

In US Units:

$$T = \frac{60}{10} = 6 \text{ minutes}$$

$$Vol_1 = T\left(\frac{Q_{in}}{Q_{p1}}\right)(Q_{p1} - Q_{in})$$

$$Vol_1 = 6\left(\frac{159}{318}\right)(318 - 159)$$

$$Vol_1 = 477 \text{ cubic feet}$$

Vol_2 is calculated with the following equation. An iteration or trial and error show that the shortest cycle time occurs for $Q_{in} = 200$ l/s (424 cfm).

$$Vol_2 = T(Q_{in} - Q_{p1})\frac{(Q_{p2} - Q_{in})}{(Q_{p2} - Q_{p1})}$$

$$Vol_2 = 6(424 - 318)\frac{(535 - 424)}{(535 - 318)}$$

$$Vol_2 = 325 \text{ cubic feet}$$

Thus, the minimum sump volume is:
$Vol_{tot} = Vol_1 + Vol_2 = 802$ cubic feet for this example.

Minimum Sump Volume Sequence 2

The pumps start as in sequence 1. The difference here is that all pumps continue to run until the liquid reaches the low level shut off. The calculation for Vol_1 is the same as for sequence 1; however, the following equation must be used for Vol_2 (only for two pumps).

$$T = \left(\frac{Vol_1}{Q_{in}} + \frac{Vol_2}{Q_{in} - Q_{p1}} + \frac{Vol_1 + Vol_2}{Q_{p2} - Q_{in}}\right)$$

Where:

T = Pump cycle time in minutes.

Vol_1 = Active sump volume for pump 1, liters (cu ft).

Vol_2 = Active sump volume for pump 2, liters (cu ft).

Q_{in} = The inflow into the station in l/min (cfm).

Q_{P1} = Flow rate with pump 1 running, l/min (cfm).

Q_{P2} = The combined flow rate with 2 pumps running, l/min (cfm).

Rearranging:

$$Vol_2 = \frac{T(Q_{in} - Q_{p1})(Q_{p2} - Q_{in})}{Q_{p2} - Q_{p1}} - \frac{Vol_1 Q_{p2}(Q_{in} - Q_{p1})}{Q_{in}(Q_{p2} - Q_{p1})} \quad \text{(B.2)}$$

An iteration or trial and error process is used to determine that the shortest cycle time occurs when Q_{in} = 180 l/s (381 cfm). This inflow is used to calculate the minimum Vol_2.

In Metric Units:

T = 360 seconds

$$Vol_2 = \frac{360(180 - 150)(250 - 180)}{250 - 150} - \frac{13{,}500 \times 250(180 - 150)}{180(250 - 150)}$$

Vol_1 = 13,500 liters

Vol_2 = 1,935 liters

$Vol_{TOT} = Vol_1 + Vol_2$ = 15,435 liters

In US Units:

T = 6 minutes

$$Vol_2 = \frac{6(381 - 318)(535 - 381)}{535 - 318} - \frac{477 \times 535(381 - 318)}{381(535 - 318)}$$

Vol_1 = 477 cubic feet

Vol_2 = 74 cubic feet

Total active volume is:
$Vol_{TOT} = Vol_1 + Vol_2$ = 551 cubic feet

Thus, operational sequence 2 requires less active volume than operational sequence 1.

B-4 Decreasing sump volume by pump alternation

By designing the control system for alternating pump starts, twice as many starts per hour (for a station with two operational pumps) can be obtained, reducing the sump volume by 50% and distributing the pump operating time evenly between pumps. In a critical application, a two-pump station may have an installed spare pump in addition to the main pumps. Consideration should be given to the system and application before utilizing this sump volume reduction technique.

Appendix C

Intake Basin Entrance Conditions

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 Variable speed pumps

There should be 5 to 10 diameters of straight, prismatic, and level (or nearly level) inlet pipe leading into the pump basin. The pipe should lie in a vertical plane through the pump intakes. To avoid high currents near the pump intakes, the pipe should be well above the basin floor, as shown in Figures 9.8.4, 9.8.5, 9.8.6, 9.8.7, 9.8.13, and 9.8.17.

To produce uniform flow across the entrance of the wet well during a cleaning, provide a short (approximately D/5) rectangular recess 2D wide on the upstream side of the sluice gate. Alternately, use a short transition from a circular pipe to a rectangular conduit as shown in Figure 9.8.13.

The minimum liquid level must be high enough to avoid a free fall of the liquid entering the wet well. Because the speed of the pump can be regulated to match the inflow, a stable liquid level in the wet well can be maintained to match the depth in the upstream conduit, thus avoiding a free fall.

C-2 Constant speed pumping

Constant speed pumping requires cyclic (on-off) pump operation, and there must be enough active storage volume 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 ft) for constant speed pumping applications.

Improper but common practice is to allow a free fall or cascade from the inlet into the pool below. But even a short free fall entrains air bubbles and drives them deep into the pool where they may be drawn into the pumps and reduce pump flow rate, head, and efficiency as well as cause damage to the pump. If the liquid is domestic wastewater, the turbulence sweeps malodorous and corrosive gasses into the atmosphere. The problem, in 1997, was almost universal in wet wells for constant speed pumps where the active storage requirement made it necessary to separate high and low liquid levels by, typically, 1.2 m (4 ft) to avoid excessively frequent motor starts.

C-2.1 Inlet pipe, trench-type wet wells

The objectives in designing the entrance for trench-type wet wells containing constant speed pumps are:

1) To eliminate any cascade

2) To minimize turbulence and the release of noxious dissolved gasses

3) To produce gentle, horizontal currents free from air bubbles

4) To supply a large part of the active storage volume in the inlet pipe so as to minimize the size of the wet well

Objectives 1 and 3 could be met by installing a drop manhole 5 to 10 diameters upstream from the sluice gate. Objectives 2 and 4, however, would not be met; and a drop manhole is not recommended.

C-2.2 Storage in approach pipe

All four objectives listed in C-2.1 can be achieved by installing an "approach pipe," a pipe somewhat larger than the upstream sewer and laid at a severe gradient to produce supercritical velocities at low wet well levels and thus supply a major share of the required active storage volume. The last part of the approach pipe should preferably be laid horizontally and must meet the other conditions in C-1 above. A gradient of 2% is a good choice because:

1) A pipe 60 m (200 ft) long allows the liquid level to fluctuate 1.2 m (4 ft)

2) Such a pipe can hold half or more of the active storage volume required

3) supercritical velocities are reasonable and produce a weak hydraulic jump where the supercritical flow strikes the pooled water

The Froude number for the jump is less than 2.5, so there is little bubble formation and off-gassing. Note from Tables C.1 and C.2 that the useful active storage cross-section of the approach pipe varies from 72 to 81% of the total pipe cross-sectional area.

To flush deposits from the approach pipe, set the stop level for each pump (or combination of pumps) to produce an approach pipe exit velocity of 1.0 to 1.2 m/s (3.0 to 4.0 ft/s).

Tables C.1 and C.2, developed by Wheeler (1995), contains data for approach pipes at 2% gradient based on a modified Manning's n of 0.010 (roughly equivalent to a constant n of 0.013). The allowable flow is predicated on a sequent depth (after the jump) of 60% of the pipe diameter. The energy grade line (EGL) before the jump is about 25% of the pipe diameter (D_p) below the soffit, so the hydraulic jump can never reach the top of the pipe. There is a 20 D_p length of free water surface so that any bubbles formed in the hydraulic jump can rise to the surface and escape up the pipe.

Smoother pipes and steeper slopes generate higher velocities, larger Froude numbers upstream from the jump, and higher sequent depths than do flatter slopes or rougher pipe. To maintain a sequent depth of 60% of the pipe diameter, it follows that for a given size and slope, a rough approach pipe can carry a larger flow than a smooth one.

C-3 Transition manhole, sewer to approach pipe

The transition in the manhole between the upstream conduit and the approach pipe is designed to acceler-

Table C.1 — Maximum flow in approach pipes with hydraulic jump—metric units, slope = 2%, Manning's n = 0.010[a]. Sequent depth = 60% pipe diameter. After Wheeler (1995).

True Pipe		Flow Rate		Before Jump				After Jump	
Dia. D_P mm	Area A_t m^2	m^3/h	l/s	y/D_P %[b]	Velocity m/s	A_e/A_t %[c]	Froude Number	y/D_P %[b]	Energy Loss %
254	0.051	71	20	32	1.4	72	1.6	59	17
304	0.073	110	31	32	1.6	72	1.6	59	18
381	0.114	190	53	31	1.8	74	1.7	60	18
457	0.164	290	81	30	2.0	75	1.7	60	18
533	0.223	420	120	29	2.2	76	1.7	60	19
610	0.292	580	160	29	2.3	76	1.8	60	19
686	0.370	770	210	28	2.5	77	1.8	60	20
762	0.456	990	270	28	2.6	78	1.8	60	20
838	0.552	1200	340	27	2.8	78	1.9	60	20
914	0.657	1500	420	27	2.9	78	1.9	60	21
1067	0.894	2200	610	27	3.2	78	1.9	60	21
1219	1.17	3000	840	26	3.5	79	2.0	60	22
1372	1.48	4000	1100	26	3.7	79	2.0	60	22
1524	1.82	5100	1400	25	4.0	79	2.0	60	23
1676	2.21	6500	1800	25	4.2	81	2.1	60	23
1829	2.63	7900	2200	25	4.4	81	2.1	60	24

[a] For n = 0.009, multiply flow rates by 92%.
For n = 0.011, multiply flow rates by 108%.
For n = 0.012, multiply flow rates by 115%.
For n = 0.013, multiply flow rates by 122%.

[b] Depth (y) divided by pipe diameter (D_p) expressed in percent.

[c] Empty area of pipe above liquid level (A_e) divided by total area (A_t).

ate the liquid to the velocities 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 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 plus velocity head above the invert, and the sum is usually about 75% D_p.

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. Velocities 20% greater than the values in Tables C.1 and C.2 increase the sequent depth from 60 to only 67% D_p — an increase readily tolerated.

C-4 Sluice gate

A mechanically-operated sluice gate must be installed at the entrance to the wet well both to protect the station and to regulate the flow required for cleaning. The mechanism should be capable of setting the elevation of the sluice gate accurately and rapidly to a predetermined position.

C-5 Lining

The approach pipe is subject to corrosion caused by sulfuric acid forming above low liquid line by bacteria acting upon sulfur compounds. As with the wet well, all surfaces above low liquid level should be lined with an impervious material immune to corrosion.

Table C.2 — Maximum flow in approach pipes with hydraulic jump—US customary units, slope = 2%, Manning's n = 0.010[a]. Sequent depth = 60% pipe diameter. After Wheeler (1995).

Pipe		Flow Rate		Before Jump				After Jump	
Dia. D_P inch	Area A_t ft^2	mgd	ft^3/s	y/D_P %[b]	Velocity ft/s	A_e/A_t %[c]	Froude Number	y/D_P %[b]	Energy Loss %
10	0.55	0.5	0.7	32	4.6	72	1.6	59	17
12	0.79	0.7	1.1	32	5.1	72	1.6	59	18
15	1.23	1.2	1.9	31	5.8	74	1.7	60	18
18	1.77	1.9	2.9	30	6.5	75	1.7	60	18
21	2.41	2.7	4.1	29	7.1	76	1.7	60	19
24	3.14	3.7	5.7	29	7.7	76	1.8	60	19
27	3.98	4.9	7.5	28	8.2	77	1.8	60	20
30	4.91	6.3	9.7	28	8.7	78	1.8	60	20
33	5.94	7.8	12.1	27	9.2	78	1.9	60	20
36	7.07	9.7	14.9	27	9.7	78	1.9	60	21
42	9.62	14.0	21.6	27	10.6	78	1.9	60	21
48	12.6	19.1	29.6	26	11.4	79	2.0	60	22
54	15.9	25.3	39.1	26	12.2	79	2.0	60	22
60	19.6	32.5	50.3	25	13.0	79	2.0	60	23
66	23.8	40.9	63.3	25	13.7	81	2.1	60	23
72	28.3	50.3	77.8	25	14.4	81	2.1	60	24

[a] For n = 0.009, multiply flow rates by 92%.
For n = 0.011, multiply flow rates by 108%.
For n = 0.012, multiply flow rates by 115%.
For n = 0.013, multiply flow rates by 122%.

[b] Depth (y) divided by pipe diameter (D_p).

[c] Empty area of pipe above liquid level (A_e) divided by total area (A_t).

C-6 Design examples

Examples of wet well designs for

1) Variable speed pumps

2) Constant speed pumps

3) Approach pipes

4) Transition manholes

are given by Sanks, Tchobanoglous, Bosserman, and Jones (1998).

Tables C.1 and C.2 can be modified to other flows, pipe gradients, or roughness by means of the PARTFULL®, program (1995), which can be obtained free from Wheeler.

Appendix D

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

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Appendix C

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Appendix E

Index

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

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

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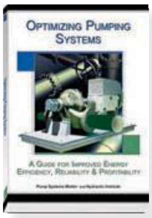

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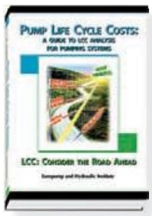

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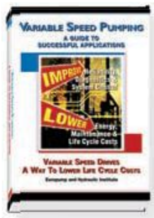

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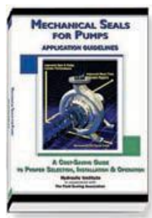

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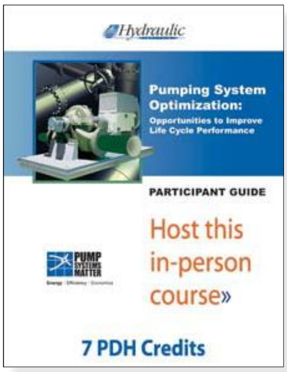

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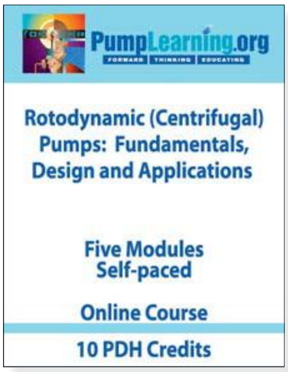

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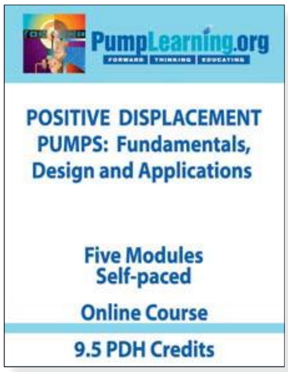

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