# Appendix F: Water and Sewer Separation Requirements and Solutions City of Portland Bureau of Water Works 5/21/03

# Water & Sewer Line Separation Requirements and Solutions

Protection of the water system is mandatory. Sanitary sewer mains and their appurtenances must not physically contact the public water system.

| **Water main construction near existing sewers** | **Sewer main construction near existing water facilities** |
|---|---|
| OAR 333-061-0050 (9, 10) | OAR 340-052, Appendix A (1)(i) and (2)(i) |
| • OR State Dept of Human Services (DHS) Drinking Water Program | • OR Dept of Environmental Quality (DEQ) |
| | • OAR 340 parallels and cites compliance with OAR 333 |

*Skin-to-skin clearances and separation requirements for both OAR's are generally the same. Zones are different though.*

## Skin-to-Skin Clearances

| | |
|---|---|
| **Crossings:** Water main must be 1.5' min above the sewer main with one full pipe length centered over the sewer so joints are max distance. | **Crossings:** Sewer main must be 1.5' min. below the water main and adequate structural protection for each line is provided. |
| **Parallel trenches:** Water main must be more than 10 feet horizontal clearance; or more than 5 feet horizontal clearance with at least 1.5' vertical clearance over the sewer | **Parallel trenches:** Sewer main must be more than 10 feet horizontal clearance; or more than 5 feet horizontal clearance with at least 1.5' vertical clearance under the water |

**Zone Limits**

| | |
|---|---|
| • **Zone 1:** more than 10 feet horizontal clearance or 5' min horizontal clearance with 1.5' min vertical clearance | • **Zone 1:** more 10 feet horizontal clearance or 5' min horizontal clearance with 1.5' min vertical clearance |
| • **Zone 2:** from 1 foot to 5 foot horizontal clearance with water above the sewer with at least 1.5 feet vertical clearance | • **Zone 2:** from 1 foot to 5 foot horizontal clearance with water above the sewer with at least 1.5 feet vertical clearance |
| • **Zone 3:** 1 foot or less horizontal clearance with water above sewer 1.5 feet vertical clearance | • **Zone 3:** 1 foot or less horizontal clearance with water above or below sewer (i.e. on top of each other) |
| • **Zone 4:** less than 10 feet horizontal clearance with water less than 1.5 feet above the sewer, including same elevation or even below the sewer | • **Zone 4:** less than 10 feet horizontal clearance with less than 1.5' min vertical clearance, or sewer at same level above water |

<table>
<tr><th colspan="2">Variances</th></tr>
<tr><th>Crossings</th><th>Crossings</th></tr>
<tr><td>• Water <u>above</u> sewer with less than 1.5' vertical clearance</td><td>• Sewer crossing under water line with less than 1.5' vertical clearance</td></tr>
<tr><td>Expose the sewer line joints and determine condition of sewer<br><br>➢ If sewer appears to be in good condition with no evidence of leakage, then the 1.5-foot separation may be reduced; center one length of the water line at the crossing; and prepare a written proposal for approval.<br><br>➢ If the sewer conditions are not favorable or finds evidence of leakage, the sewer line shall be replaced with a full length of pipe centered at the crossing point, use acceptable pressure rated pipe material; and prepare a written proposal for approval.<br><br>Note: concrete sewer pipe is consider unfavorable since it is permeable</td><td>➢ Replace the sewer line with pressure pipe materials, center a full length of pipe at the crossing point, provide adequate structural support on both pipes to ensure neither line settles onto the other pipe; and prepare and submit for approval written report of the findings, reasons for reducing the separation; course of action proposed. Approval by BWW and/or DHS</td></tr>
<tr><td>• Water line crossing <u>under</u> sewer:<br>➢ replace the water line with a full length of pipe centered at the crossing point;<br>➢ replace the sewer using acceptable pressure rated pipe material or encase water line;<br>➢ provide structural support so sewer does not settle on water or cause leakage contamination; and<br>➢ prepare a written proposal of the findings, reasons for reducing the separation and course of action to be taken. Must be approved by BWW Regulatory Compliance and/or DHS</td><td>• Sewer crossing <u>over</u> water line –<br>➢ replace the sewer line with a full length of pipe centered at the crossing point;<br>➢ replace sewer using acceptable pressure rated pipe material or encase water line;<br>➢ provide structural support so sewer does not settle on water or cause leakage contamination;<br>➢ prepare a written proposal of the findings, reasons for reducing the separation; course of action taken; and<br>➢ take any other precautions directed by BWW Regulatory Compliance and/or DHS</td></tr>
<tr><th>Parallel trenches</th><th>Parallel trenches</th></tr>
<tr><td>• Zone 1: Main can be installed with no special requirements</td><td>• Zone 1: Main can be installed with no special requirements provided</td></tr>
</table>

| | | |
|---|---|---|
| • **Zone 2:** Approval on case-by-case basis with justification. Determine condition of sewer, replace or encase. Prepare a written report of the findings, reasons for reducing the separation; course of action taken. Documentation must be put in file. | | • **Zone 2:** Approval on case-by-case basis with justification. Water line should be located on undisturbed earth bench. |
| • **Zone 3:** Prohibited | | • **Zone 3:** Prohibited |
| • **Zone 4:** Prohibited – however, waiver may be granted by DHS provided you can mitigate by replacing sewer pipe with pressure pipe and encase water. Approval for a waiver from the construction standards by DHS is considered on case-by-case basis with justification. Submit waiver request to DHS through BWW Regulatory Compliance. Documentation must be kept put in project file. | | • **Zone 4:** Prohibited, if waiver granted, replace the sewer line with pressure pipe materials and prepare and submit for approval written report of the findings, reasons for reducing the separation; course of action proposed Approval for a waiver from the construction standards by DHS is considered on case-by-case basis with justification. Submit waiver request to DHS through BWW Regulatory Compliance. Documentation must be kept put in project file. |

New water and sewer construction should be designed to comply with the OAR. In the event that new construction encounters existing water or sewer facilities during construction, a written proposal for variance must submit a written proposal to BWW for approval of how they propose to resolve any OAR water and sewer line separation conflicts. Proposal should include written description of why variance in needed, including horizontal and vertical location of water and sewer, skin-to-skin clearances, type of sewer pipe material, condition of sewer pipe, and proposed solution.

Below is a list of DHS acceptable sewer pipe material for crossings or in parallel alignments where alternative solutions for compliance are needed. These are pressure-rated pipes with watertight joints.

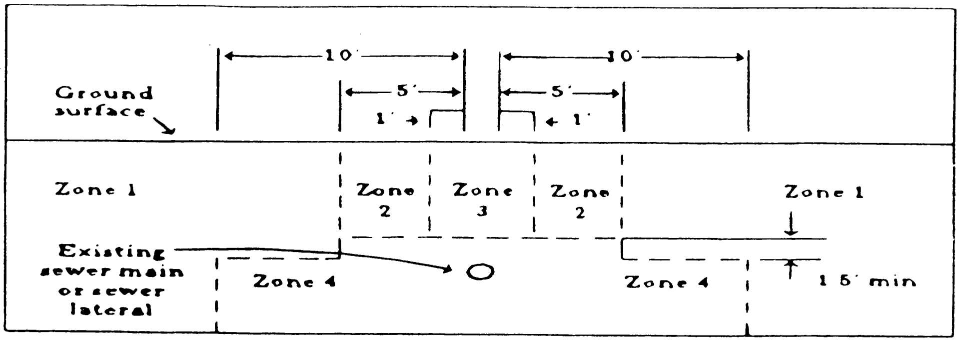
- PVC pressure pipe (ASTM D-2241, SDR 32.5),
- High-density PE pipe (Drisco pipe 1000, PE 3406, SDR 32.5, 125 psi or better),
- Ductile-iron Class 50 (AWWA C-51),
- Other acceptable pipe as approved by DHS;
- or the sewer shall be encased in a reinforced concrete jacket for a distance of 10 feet on both sides of the crossing.

Possible solutions to be resolve OAR 333 or OAR 340:

1. Move alignment
2. Raise profile
3. Encase sewer 10 feet each side of crossing using alternative pressure pipe material for either water or sewer
4. Encase water 10 feet each side of crossing
5. Replace the existing water or existing sewer
6. Seal, encase water joints; eliminate points where contamination could occur
7. Structurally support water and/or sewer lines to prevent settlement that could cause leakage contamination.
   - Extend casings for sewer into manholes
   - Construct reinforced concrete pad or steel structure under pipe on both sides of crossing to bear load

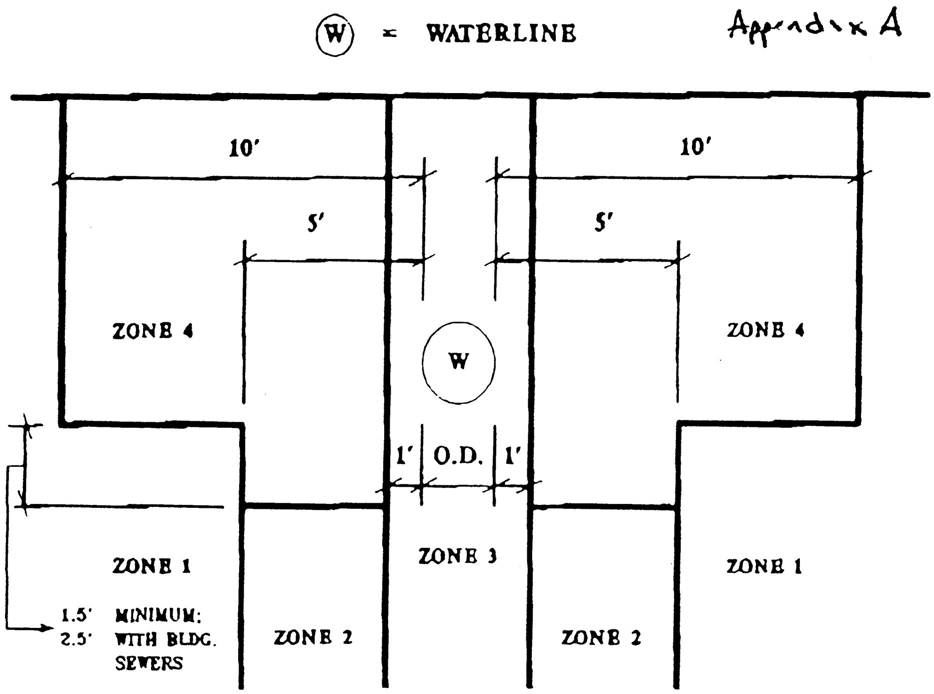
Figure 1: Water Line-Sewer Line Separation

OAR 333-061-0050(10)




Zone 1: Only crossing restrictions apply
Zone 2: Case-by-case determination
Zone 3: Parallel water line prohibited
Zone 4: Parallel water line prohibited

OAR 340-052 Appendix A




**SEWER LINE ZONES**

ZONE 1 SEWER LINE CAN BE LAID IN THIS AREA WITH NO SPECIAL REQUIREMENTS OF EITHER CONSTRUCTION OR MATERIALS.

ZONE 2 INSTALLING A SEWER LINE IN THIS ZONE IS NOT ADVISABLE AND MUST BE JUSTIFIED IN EACH CASE. WATER LINE SHOULD BE LOCATED ON A BENCH OF UNDISTURBED EARTH WHEN CONSTRUCTED CONCURRENTLY IN A COMMON TRENCH WITH SEWER LINE.

ZONE 3 INSTALLING A SEWER MAIN DIRECTLY OVER A WATER MAIN OR DIRECTLY UNDER A WATER MAIN IN THIS ZONE IS PROHIBITED SINCE TAPPING AND O. & M. OF EACH LINE WOULD BE IMPAIRED.

ZONE 4 SEWER LINE CONSTRUCTION IN THIS ZONE WOULD GENERALLY NOT BE PERMITTED. EACH INSTALLATION MUST BE JUSTIFIED. IF CONSTRUCTION WAS PERMITTED, PRESSURE PIPE MATERIALS FOR THIS SEWER LINE WOULD BE REQUIRED.

Effective 9-1-81

*FIGURE A-1*

SEPARATION OF PARALLEL WATER-SEWER LINES

# Appendix G: Utilities Installations/Pipeline Installation Procedures for Crossings Union Pacific Railroad

**Real Estate & Utility Specifications**

# Utilities Installations

## Installations: Types and Definitions

Installations, either pipeline or wireline, may be considered encroachments, crossings, or both.

An **encroachment** is a pipeline or wireline that enters the railroad company's right-of-way and either does not leave the right-of-way or follows along the right-of-way for some distance. These installations should follow **Procedures for Encroachments.**

A **crossing** is a pipeline or wireline that enters the railroad company's trackage from one side of the right-of-way to the other side of the right-of-way in as near a straight line as possible. These installations should follow **Procedures for Pipeline Crossings** or **Procedures for Wireline Crossings.** Or, you may use our new **online application process.**

This online application process will allow you to complete an application for a wireline or a pipeline crossing electronically, and will save you time and money - avoiding the delays, expense and uncertainty of mailing applications to us. Due to the complexities of encroachments you cannot submit an online application for an encroachment

If an installation entails **both an encroachment and a crossing**, procedures for both must be followed. However, only one **Application Form** [6K PDF] needs to be filled out. This single application must be accompanied by both the appropriate Exhibit "A" document (describing the crossing) and complete engineering plans (detailing the encroachment).

### Not Sure Where to Start?

Select the appropriate set of "Procedures" from the links above (pipeline or wireline – encroachment or crossing). The procedures information will include a detailed outline of the application process from start to finish, including which forms you will need, how to print copies of them, and where to send them once they have been completed, unless you use our online application process which is self explanatory.

If you have followed this process before and know which documents you need, you may select them from the list below, or you may use our new **online application process.**

### Procedures and Application Forms

The minimum that you must submit to the **Contact Person**:

- **Application Form**
- A map indicating the general location of the crossing (a city street map or county map upon which you have marked the location of the installation), and
- Exhibit A (Choose applicable form below).

### Pipeline Installation

**Exhibit "A" – Flammable** [177K PDF]
Form: Print a copy, complete, and mail or fax

### Wireline Installation

**Exhibit "A" - Overhead Wireline Crossing**
**750 Volts or Less** [141K PDF] Form: Print a copy, complete,

**Exhibit "A" – Non-Flammable** [179K PDF]
Form: Print a copy, complete, and mail or fax

**Exhibit "A" – Gas Line** [101K PDF]
Form: Print a copy, complete, and mail or fax

**Completed Exhibit "A"** Sample Copy [42K GIF]

**Engineering Specifications**

**Exhibit "A" - Overhead Wireline Crossing Over 750 Volts** [163K PDF] Form: Print a copy, complete, an

**Exhibit "A" – Underground Wireline Crossing 750 Volts or Less** [142K PDF] Form: Print a copy, complete,

**Exhibit "A" – Underground Wireline Crossing Over 750 Volts** [152K PDF] Form: Print a copy, complete, an

**Completed Exhibit "A"** Sample Copy [37K GIF]

**Engineering Specifications**

Optional Service
For Rush Handling (applicable for crossings only):

- **Rush Application Form** [4K PDF], (print a copy, complete and mail with check), and
- Rush Fee of $3,055

## Additional Information

Applicable to both Pipeline and Wireline Installations

**Wireline/Pipeline Encroachment Planning Guide and Construction Procedures**

**Minimum Safety Requirements for Contractors**

**Railroad Protective Liability Insurance**
Information on coverage through a blanket policy offered through UPRR: rates and application form.

**Pipeline, Wireline, Right of Entry and Drainage Contacts**

### Viewing/Printing PDF Files

To view PDF files you will need the Adobe Acrobat Reader plug-in. If you do not have this plug-in, it is available as a free download from the **Adobe Web site.**

**Real Estate & Utility Specifications**

# Pipeline Installation
# Procedures for Crossings
## Procedures for New Pipeline Crossings

1. If it is necessary to enter the railroad company's property to conduct a survey for the completion of required location information in this application, the **Permit To Be On Railroad Property for Utility Survey** [13K PDF] form must be printed, executed and returned following the instructions given in the permit.

2. You may complete our **online application process** and avoid the time delays, expense and uncertainty of mailing the application to us. Or, you may continue to use the old process whereby the **Application** [8K PDF] and the appropriate Exhibit "A" document must be printed and completed in their entirety. Choose the appropriate Exhibit "A" to accompany your application from the following:

   - **Exhibit "A" - Flammable** [177K PDF]
   - **Exhibit "A" - Non-Flammable** [179K PDF]

   Failure to complete Exhibit "A" merely delays the review process of the entire application. Please review the **Sample Copy of Completed Exhibit "A"** [42K GIF] which is provided to enable you to complete the form as accurately as possible. In addition, any application not conforming to railroad minimum standards, as defined in the **Engineering Specifications**, will delay processing. If there is a valid reason why compliance with the railroad standards is not possible, these reasons must be clearly explained or the application will be rejected and returned to you for further explanation. You must complete the question on the Exhibit "A" that indicates you have called the Fiber Optic Hot Line and include the ticket number that you have been given.

3. If possible, please provide a city, county or topographical map of the area, showing the proposed installation.

4. When using a street name on the application that has been changed, please include the current name as well as any previous name. Many of the old railroad company maps do not reflect these name changes.

5. Please refer to the information on **Fixed Object Identity** [22K GIF] for examples to assist you in locating "fixed objects." Your crossing must be tied to one of these objects.

6. Applications should be submitted to the appropriate individual within the Real Estate Department. Select the representative for your region from the map of **Pipeline, Wireline, Right of Entry and Drainage Contacts**, and address the application to:

   [Name of Your Region Representative]
   Union Pacific Railroad Company
   1400 Douglas Street, Mail Stop 1690
   Omaha, Nebraska 68179

7. Applications will be required for all proposed crossings of the railroad company's right-of-way. If you are a public utility and it is your proposal to cross railroad right-of-way within a dedicated public right-of-way, you must provide documentation from city or county records that identify and prove the dedication of such public way.

8. Generally, agreement processing time will be approximately 30 to 45 days. Please allow sufficient lead time for document handling prior to desired construction date. Before construction begins, agreements must be executed by the Licensee and Contractor, if applicable, and returned to this office. **Verbal authorizations will not be permitted or granted.** Generally, a minimum of 48 hours' advance notice after execution of an agreement will be required prior to entry.

9. License fees and insurance certificates, if required, must be submitted at the time you execute and return the agreement. Because license fees are based on property values, we will only be able to provide you with fee information after your application has been reviewed and approved.

10. If you require rush handling of your application, please print a copy of the **Rush Handling** form [5K PDF], complete and return the form in an envelope labeled "RUSH."

11. Depending on the scope of the work and proximity to our tracks we may require that Railroad Protective Liability Insurance be obtained, in addition to general liability insurance. We have acquired a blanket Railroad Protective Liability Insurance policy which may allow inclusion of your project under our coverage for an additional charge. We've found that in many instances it may be cheaper for the contractor do this than to obtain their own coverage. However, we do encourage you to shop around, as you may find a more favorable rate. An application form and additional information on **Railroad Protective Liability Insurance** through UPRR can be found in this section.

12. **Note: Applications will only be accepted that are prepared on our standard application form identified as Exhibit "A."**

13. Questions? Need Assistance? Check the map of **Pipeline, Wireline, Right of Entry and Drainage Contacts** for the names of those who can help.

**Viewing/Printing PDF Files**
To view PDF files you will need the Adobe Acrobat Reader plug-in. If you do not have this plug-in, it is available as a free download from the **Adobe Web site.**

**Real Estate & Utility Specifications**

# Pipeline Installation
# Engineering Specifications

**Specifications for Pipelines with Maximum Casing Diameter Of 48 Inches and Encased Gas Transmission Lines Crossing Under Railroad Tracks**

A. **For Flammable Substances**

1. **Scope**
   Pipelines included under these specifications are those installed to carry oil, gas, gasoline, or other Flammable or highly volatile substances.

2. **Installation**
   Pipelines under railroad track and right-of-way shall be encased in a larger pipe or conduit installed as indicated in **Fig. 1**.

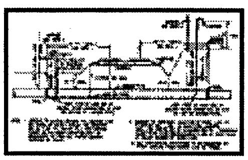
   

   **FIGURE 1**
   [19K GIF]

   The casing pipe or conduit is the essential feature of the plan. Some of the other features as described in following paragraphs are optional in certain cases.

3. **Carrier Pipe**
   Carrier pipe inside of casing under railroad Track and right-of-way shall be of good construction of steel, wrought iron, cast iron, pure or alloyed iron; and shall be either seamless or substantially welded pipe, with welded coupling, or other "approved" joints. Pipe shall be laid with slack (no tension or compression) in the line. Use of a carrier pipe of material other than the above mentioned iron or steel must be approved by the chief engineer of the railroad.

4. **Casing Pipe**
   Casing pipe and joints shall be uniformly thick steel construction approved by the railroad's chief engineer and shall be capable in its entirety of withstanding load of railroad roadbed, track and traffic; also shall be constructed so as to prevent leakage of any matter from the casing or conduit throughout its length under track and railroad right-of-way.

   The casing shall be installed with even bearing throughout its length, and to prevent formation of standing liquids shall slope to one end.

   Wall thickness of the casing must be no less than that specified in the attached steel casing pipe wall thickness chart.

   Inside diameter of the casing shall be at least 10% larger than the outside diameter of the carrier pipe but no less than 2 inches greater than largest outside diameter of carrier pipe, joints or couplings.

5. **Cathodic Protection**
   Where cathodic protection is used on the carrier pipe, an above ground test box constructed specifically for this purpose will be provided adjacent to casing vent pipe with test wires attached to casing wall and carrier pipe, as shown in Fig. 1.

6. **Seals and Vents**
   Where ends of casing are below ground, they shall be suitably sealed to outside of carrier pipe against intrusion of foreign material which might prevent ready removal of the carrier pipe. Also, the casing must be properly vented above ground with vent pipes having inside diameter equal to 10% of nominal size of the carrier pipe but no less than 2 inches and extending not less than 4 feet above ground surface. Vent pipe at low end of casing shall be connected with bottom of casing and vent at high end shall be connected with top of casing. Top of vent shall be fitted with down-turned elbow properly screened.

7. **Depth of Casing**
   The depth from base of railroad rail to top of casing at its closest point shall not be less than 4.5 feet and on other portions of railroad right-of-way where casing is not directly beneath any track the depth from surface of right-of-way, and from bottom of ditches to top of casing, shall not be less than 3 feet. Where it is not possible to secure the above depths, special construction shall be used as approved by the railroad's chief engineer.

8. **Length of Casing**
   Casing shall extend at least 45 feet or 2(D)+20 feet, (where "D" equals depth of the bottom of the casing below railroad subgrade), whichever is greater, each side from (measured at right angles to) centerline of outside track. The casing is to extend beyond the limit of the railroad right-of-way as required to obtain the specified length. If additional tracks are constructed in the future, the casing shall be correspondingly extended at the utility's expense. When a carrier pipe other than iron or steel is allowed, then the pipe must be encased in steel for its entire length on railroad right-of-way or that length determined above, whichever is greater.

9. **Jacking Pits**
   Jacking pits shall be a minimum of 30 feet from the centerline of track.

10. **Shut-Off Valves**
    Where warranted by special local conditions as determined by the railroad company, accessible emergency shutoff valves shall be installed within effective distances at each side of the crossing.

11. **Location**
    Pipelines shall where practicable, be located to cross tracks at approximately right angles thereto and said crossing shall not be closer than 50 feet to any portion of any railroad bridge, building, or other important structure, nor to any switch unless specifically approved by the chief engineer.

    Pipelines, casing pipe and vent pipes shall be at least 16 feet (vertically) from aerial electric wired and shall be suitably insulated from underground conduits carrying electric wires on railroad right-of-way.

12. **Topography**

Pipelines carrying extremely high pressure, volatile or highly flammable material shall, where practicable, be located where the ground surface slopes downward away from the railroad tracks. Also, when large capacity pipes are located where the ground surface ascends above the railroad roadbed, there must be sufficient adjacent opening under the tracks to carry off the material in event of rupture.

13. **Restoration of Right-of-Way**
Upon completion of the pipeline installation work, all rubbish, excess materials, temporary structures and equipment are to be removed and the railroad's right-of-way cleaned and restored to the satisfaction of the railroad's chief engineer or his authorized representative. Disturbed areas shall be seeded or otherwise protected to control erosion as specified by the chief engineer of the railroad.

14. **Approval of Plans**
Plans for a proposed pipeline shall be submitted to and meet the approval of the chief engineer of the railroad or his authorized representative before work is begun and all work on railroad right-of-way, including the supporting of the track or roadbed, shall be subject to his inspection and direction. All costs incurred shall be borne by the utility.

B. **For Non-flammable Substances**

1. **Scope**
Pipelines included under these specifications are those installed to carry steam, water or any nonflammable substance which from its nature or pressure might cause damage if escaping on or in the vicinity of railroad property.

2. **Installation**
Pipelines under railroad track and right-of-way shall be encased in a larger pipe or conduit installed as indicated in Fig. 2.

The casing pipe or conduit is the essential feature of the plan. Some of the other features as described in following paragraphs are optional in certain cases.

3. **Carrier Pipe**
Carrier pipe inside the casing under the railroad track and right-of-way shall be of good construction approved by the chief engineer of the railroad.

4. **Casing Pipe**
Casing pipe and joints may be of any conduit construction approved by the railroad's chief engineer and shall be capable of withstanding the load of railroad roadbed, track and traffic; also shall be constructed so as to prevent leakage of any matter from the casing or conduit throughout its length under track and railroad right-of-way. The casing shall be installed so as to prevent the formation of a waterway under the railroad.

Casing shall be installed with even bearing throughout its length and shall slope to one end.

Wall thickness of the casing must be no less than that specified in the attached steel casing pipe wall thickness chart.

The inside diameter of the casing shall be no less than 2 inches greater than largest outside diameter of carrier pipe, joints or couplings.

5. **Cathodic Protection**
   Where cathodic protection is used on the carrier pipe, a flush test box constructed specifically for this purpose will be provided with test wires attached to casing wall and carrier pipe, as shown in **Fig. 2**.

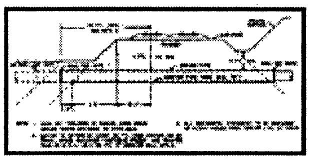


**FIGURE 2**
[11K GIF]

6. **Seals**
   The ends of the casing shall be suitably sealed to outside of carrier pipe against the intrusion of foreign material which might prevent ready removal of the carrier pipe.

7. **Depth of Casing**
   The top of the casing pipe shall be below the frost line, and its closest point shall not be less than 4.5 feet below base of railroad rail. On other portions of the railroad right-of-way where casing is not directly beneath any track the depth from the surface of the ground and from bottom of ditches to top of casing, shall not be less than 3 feet. Where it is not possible to secure the above depths, special construction shall be used as approved by the railroad's chief engineer.

8. **Length of Casing**

   Casing shall extend at least 30 feet or 2(D)+20 feet, (where "D" equals depth of the bottom of the casing below railroad subgrade), whichever is greater, each side from (measured at right angles to) centerline of outside track. The casing is to extend beyond the limit of the railroad right-of-way as required to obtain the specified length. If additional tracks are constructed in the future, the casing shall be correspondingly extended at the utility's expense.

9. **Jacking Pits**
   Jacking pits shall be a minimum of 30 feet from the centerline of track.

10. **Shut-Off Valves**
    Where warranted by special local conditions and when mutually agreed to by the railroad company and the owner of the pipeline, accessible emergency shutoff valves shall be installed within effective distances at each side of the crossing.

11. **Location**
    Pipelines shall, where practicable, be located to cross tracks at approximately right angles thereto and said crossing shall not be closer than 50 feet to any portion of any railroad bridge, building, or other important structure.

    Pipelines and casing pipe shall be at least 16 feet (vertically) from aerial electric wired and shall be suitably insulated from underground conduits carrying electric wires on railroad right-of-way.

12. **Topography**
    Where practicable, pipelines shall be located where the ground surface slopes

downward away from the railroad tracks. Also, when large capacity pipes "e located where the ground surface ascends above the railroad roadbed, there must be sufficient adjacent opening under the tracks to carry off the material in event of rupture.

13. **Restoration of Right-of-Way**
Upon completion of the pipeline installation work all rubbish, excess materials, temporary structures and equipment are to be removed and the railroad's right-of-way cleaned and restored to the satisfaction of the railroad's chief engineer or his authorized representative. Disturbed areas shall be seeded or otherwise protected to control erosion as specified by the chief engineer of the railroad.

14. **Approval of Plans**
Plans for a proposed pipeline shall be submitted to and meet the approval of the chief engineer of the railroad or his authorized representative before work is begun and all work on railroad right-of-way, including the supporting of the track or roadbed, shall be subject to his inspection and direction. All costs incurred shall be borne by the utility.

### Steel Casing Pipe Wall Thickness Chart

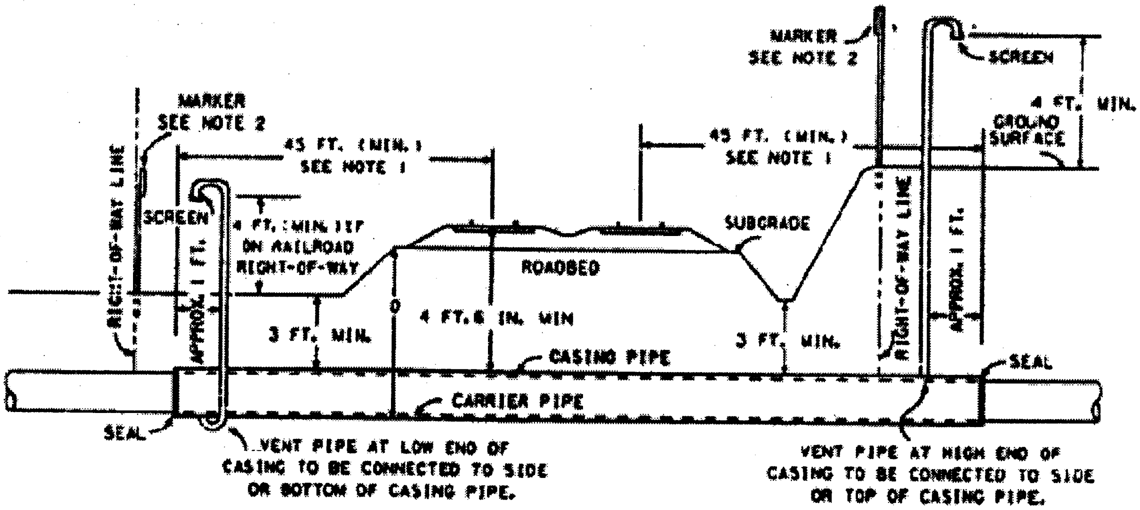
| Minimum Thickness | Diameter Of Casing Pipe |
|---|---|
| 1/4" (0.2500") | 12" or less |
| 5/16" (0.3125") | over 12"-18" |
| 3/8" (0.3750") | over 18"-22" |
| 7/16" (0.4375) | over 22"-28" |
| 1/2" (0.5000") | over 28"-34" |
| 9/16" (0.5625) | over 34"-42" |
| 5/8" (0.6250") | over 42"-48" |

This chart is only for smooth steel casing pipes with minimum yield strength of 35,000 psi.

Casing pipes larger than 48" diameter or with any portion deeper than 20' shall be submitted to chief engineer of the railroad for approval.

### Diagrams of Common and Engineering Standards

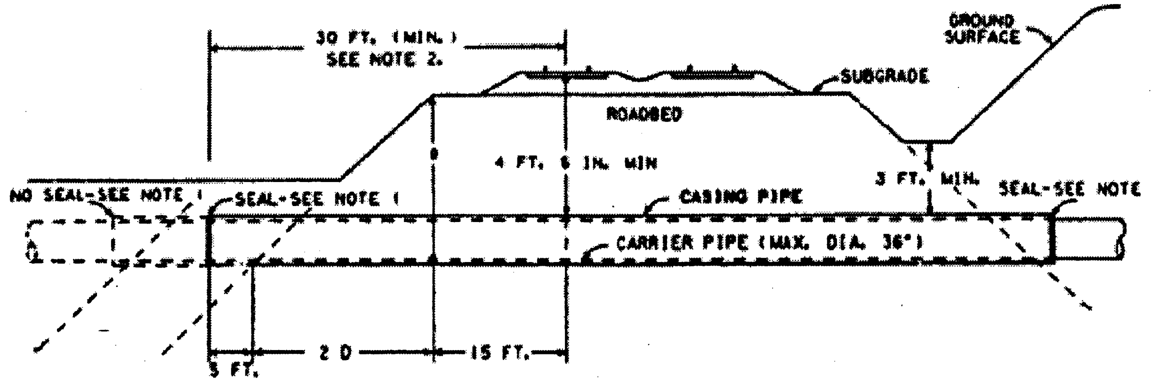
- **Fixed Object Identity** [22K GIF]
- **Mile Marker** [33K GIF]
- **Culvert Marker** [20K GIF]
- **Bridge Number Sign** [20K GIF]
- **General Shoring Requirements** [25K GIF]




NOTE: 1. CASING TO EXTEND BEYOND THE CENTER LINE OF TRACK AT RIGHT ANGLES THE GREATER OF 20 + 20 FT. OR 45 FT., AND BEYOND LIMIT OF RAILROAD RIGHT-OF-WAY IF NECESSARY TO PROVIDE PROPER LENGTH OUTSIDE OF TRACK.

2. MARKER TO INDICATE LOCATION OF PIPE LINE AT RIGHT-OF-WAY LINE. IN ADDITION, MARKERS SHALL BE INSTALLED AT MINIMUM 500-FT. INTERVALS ALONG PIPE LINE ENCROACHMENTS AND AT LOCATIONS OF MAJOR CHANGE OF DIRECTION.

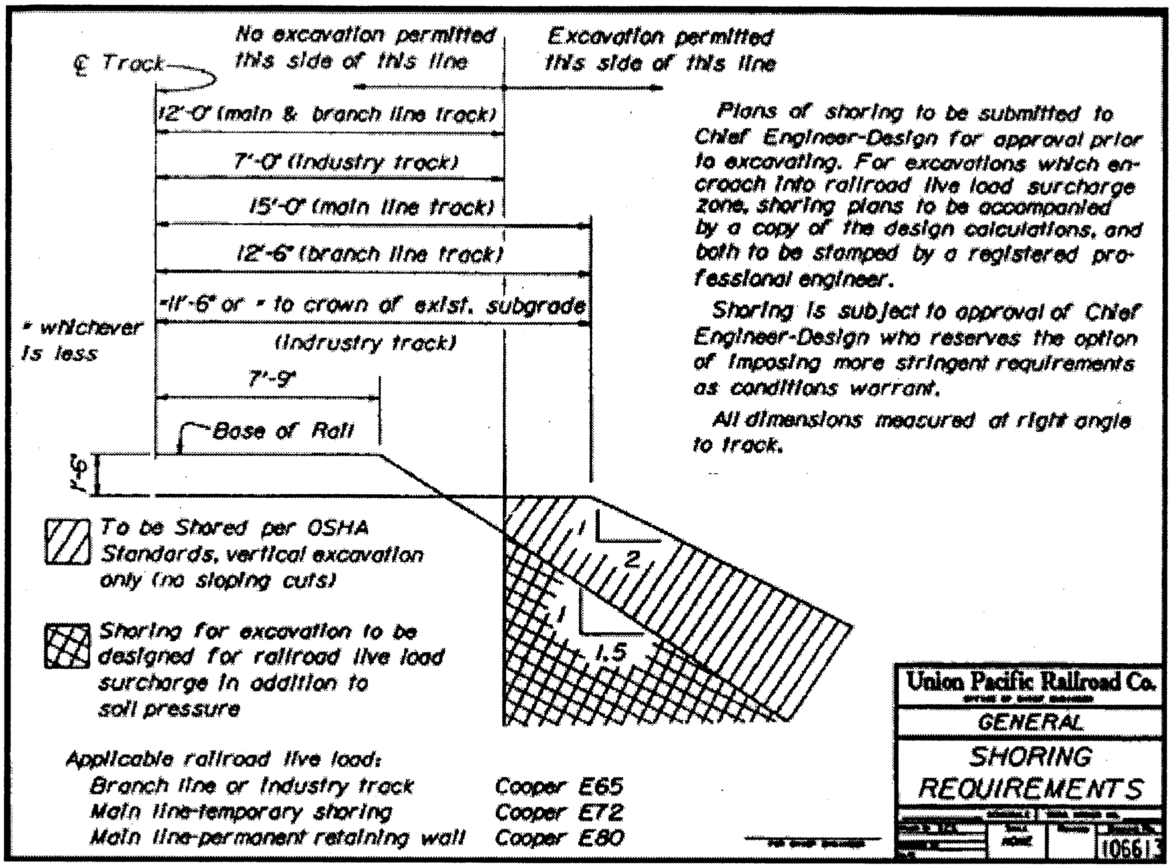
3. ALL HORIZONTAL DISTANCES TO BE MEASURED AT RIGHT ANGLES FROM CENTER LINE OF TRACK.



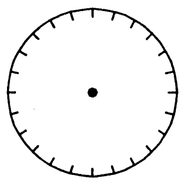

NOTE: 1. SEAL NOT REQUIRED IF CASING ENDS ABOVE GROUND WHERE DRAINAGE IS AVAILABLE.

2. CASING TO EXTEND AT LEAST 30 FT. FROM CENTERLINE OF TRACK. WHERE RAILROAD TIMETABLE SPEEDS ARE GREATER THAN 25 M.P.H. 2D + 20 FT. IF GREATER WILL APPLY.

3. ALL HORIZONTAL DISTANCES TO BE MEASURED AT RIGHT ANGLES FROM CENTER LINE OF TRACK


No excavation permitted this side of this line
Excavation permitted this side of this line
℄ Track
12'-0" (main & branch line track)
7'-0" (Industry track)
15'-0" (main line track)
12'-6" (branch line track)
*11'-6" or * to crown of exist. subgrade
(Indrustry track)
* whichever is less
7'-9"
Base of Rail
1'-6"
1
2
1
1.5
Plans of shoring to be submitted to Chief Engineer-Design for approval prior to excavating. For excavations which encroach into railroad live load surcharge zone, shoring plans to be accompanied by a copy of the design calculations, and both to be stamped by a registered professional engineer.
Shoring is subject to approval of Chief Engineer-Design who reserves the option of imposing more stringent requirements as conditions warrant.
All dimensions meacured at right angle to track.
To be Shored per OSHA Standards, vertical excavation only (no sloping cuts)
Shoring for excavation to be designed for railroad live load surcharge in addition to soil pressure
Applicable railroad live load:
Branch line or Industry track Cooper E65
Main line-temporary shoring Cooper E72
Main line-permanent retaining wall Cooper E80
Union Pacific Railroad Co.
GENERAL
SHORING REQUIREMENTS
106613

PLACE ARROW INDICATING NORTH DIRECTION RELATIVE TO CROSSING

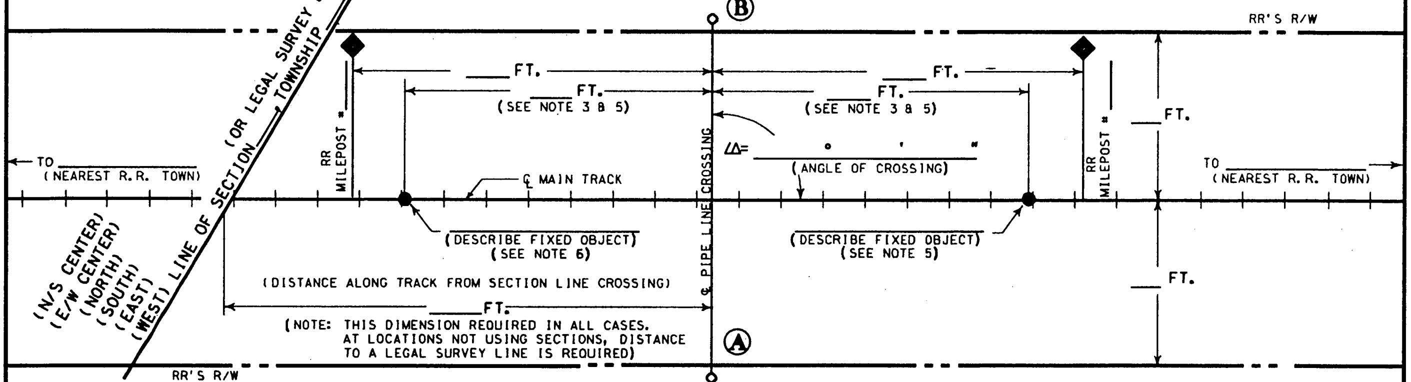


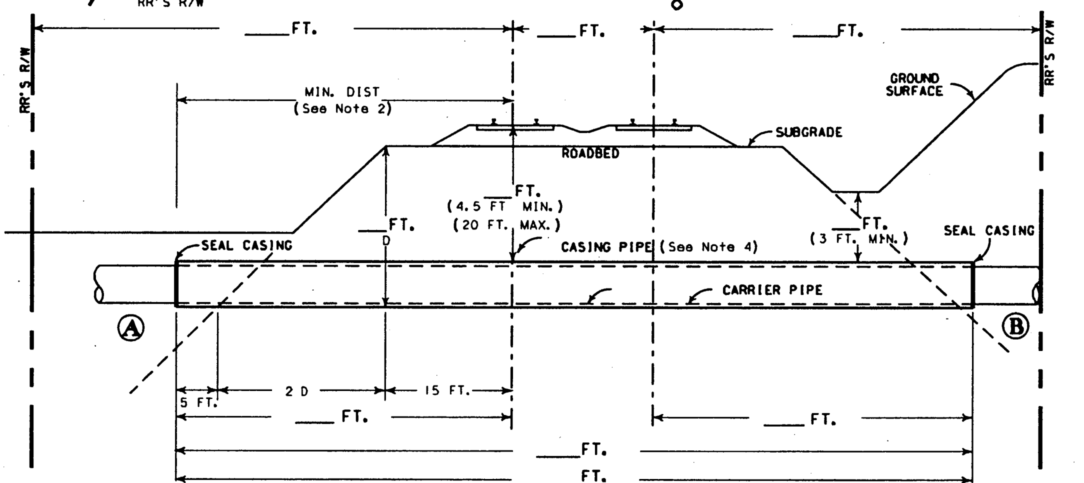
FORM DR-0404-B
REV. 5-15-98

# ENCASED NON-FLAMMABLE PIPELINE CROSSING

NO SCALE

NOTE: ALL AVAILABLE DIMENSIONS MUST BE FILLED IN TO PROCESS THIS APPLICATION.



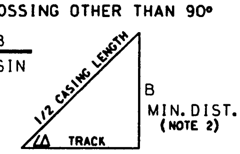




| STEEL CASING WALL THICKNESS CHART | | |
|---|---|---|
| MINIMUM THICKNESS | | DIAMETER OF CASING PIPE |
| .2500" | 1/4" | 12" OR LESS |
| .3125" | 5/16" | OVER 12"-18" |
| .3750" | 3/8" | OVER 18"-22" |
| .4375" | 7/16" | OVER 22"-28" |
| .5000" | 1/2" | OVER 28"-34" |
| .5625" | 9/16" | OVER 34"-42" |
| .6250" | 5/8" | OVER 42"-48" |
| OVER 48" MUST BE APPROVED BY R.R. CO. | | |

NOTE: THIS CHART IS ONLY FOR SMOOTH STEEL CASING PIPES WITH MINIMUM YIELD STRENGTH OF 35,000 PSI.

FORMULA TO FIGURE CASING LENGTH WITH ANGLE OF CROSSING OTHER THAN 90°

$$\frac{B}{\angle\Delta \text{ SIN}}$$




NOTES:

1) ALL HORIZONTAL DISTANCES TO BE MEASURED AT RIGHT ANGLES FROM ℄ OF TRACK.
2) CASING TO EXTEND BEYOND THE ℄ OF TRACK AT RIGHT ANGLES THE GREATER OF 2D + 20 FT., OR 30 FT., AND BEYOND LIMIT OF RAILROAD RIGHT-OF-WAY IF NECESSARY TO PROVIDE PROPER LENGTH OUTSIDE OF TRACK.
3) MINIMUM OF 50' FROM THE END OF ANY RAILROAD BRIDGE, ℄ OF ANY CULVERT, OR FROM ANY SWITCHING AREA.
4) SIGNAL REPRESENTATIVE MUST BE PRESENT DURING INSTALLATION IF RAILROAD SIGNALS ARE IN THE VICINITY OF CROSSING.
5) ALLOWABLE FIXED OBJECTS INCLUDE: BACKWALLS OF BRIDGES; ℄ OF ROAD CROSSINGS & OVERHEAD VIADUCTS (GIVE ROAD NAME), OR CULVERTS.
6) CASING AND CARRIER PIPE MUST BE PLACED A MINIMUM OF 2 FEET BELOW THE EXISTING FIBER OPTIC CABLE. ANY EXCAVATION REQUIRED WITHIN 5 FEET OF THE EXISTING FIBER OPTIC CABLE MUST BE HAND DUG.

A) IS PIPELINE CROSSING WITHIN DEDICATED STREET ?_____YES;_____NO;
B) IF YES, NAME OF STREET ________________
D) DISTRIBUTION LINE _______ OR TRANSMISSION LINE _______
C) CARRIER PIPE :
COMMODITY TO BE CONVEYED________________
OPERATING PRESSURE________PSI
WALL THICKNESS________;DIAMETER________;MATERIAL________;
E) CASING PIPE :
WALL THICKNESS________;DIAMETER________;MATERIAL________;
NOTE : CASING MUST HAVE 2" CLEARANCE BETWEEN GREATEST OUTSIDE DIAMETER OF CARRIER PIPE AND INTERIOR DIAMETER OF CASING PIPE. WHEN FURNISHING DIMENSIONS, GIVE OUTSIDE OF CARRIER PIPE AND INSIDE OF CASING PIPE.
F) METHOD OF INSTALLING CASING PIPE UNDER TRACK(S):
_____DRY BORE AND JACK (WET BORE NOT PERMITTED) ;
_____TUNNEL ; OTHER________________
G) WILL CONSTRUCTION BE BY AN OUTSIDE CONTRACTOR?_____YES;_____NO;
H) DISTANCE FROM CENTER LINE OF TRACK TO NEAR FACE OF BORING AND JACKING PITS WHEN MEASURED AT RIGHT ANGLES TO TRACK________ (30' MIN.)
I) APPLICANT HAS CONTACTED 1-800-336-9193, U. P. COMMUNICATION DEPARTMENT, AND HAS DETERMINED FIBER OPTIC CABLE_____DOES ;_____DOES NOT ; EXIST IN VICINITY OF WORK TO BE PERFORMED . TICKET NO.________________

## EXHIBIT "A"

(FOR RAILROAD USE ONLY)

UNION PACIFIC RAILROAD CO.

________________
(SUBDIVISION)

M. P __________ E. S. __________

ENCASED ____________ CROSSING AT

________________
(NEAREST CITY) (COUNTY) (STATE)

________________
(APPLICANT)

RR FILE NO.__________ DATE__________

**WARNING**

IN ALL OCCASIONS, U. P. COMMUNICATIONS DEPARTMENT MUST BE CONTACTED IN ADVANCE OF ANY WORK TO DETERMINE EXISTENCE AND LOCATION OF FIBER OPTIC CABLE.
PHONE : 1-800-336-9193

# Appendix H: Rules for Sewer Connection, City of Portland, Bureau of Environmental Services

CITY OF PORTLAND
ENVIRONMENTAL SERVICES
1211 SW Fifth Avenue, Room 800, Portland, Oregon 97204-3713 (503) 823-7740, FAX (503) 823-6995 Dean Marriott, Director

# RULES FOR SEWER CONNECTION
July 1998

Sewer connections must be made in accordance with the City's Standard Construction Specifications, the City Code, and the following rules. Any deviations must be approved by the Bureau of Environmental Services (BES). Contact BES for information on obtaining copies of the codes, provisions, and standard specifications identified in these rules of connection.

## SECTION A. GENERAL RULES

1. Sewer connection permits are required for;
   - Sewer repairs in the right of way,
   - All connections to the public sewer main and laterals,
   - Relocations of existing laterals,
   - Connections to existing laterals extended to private property
   - Construction and/or extension of branches to private property for future use

2. Sewer connection permits shall be obtained by and sewer connections shall be installed by:
   - the legal owner of the property
   - a plumbing contractor, licensed and registered with the state of Oregon and the city of Portland,
   - a sewer contractor, licensed and registered with the state of Oregon and the city of Portland.
   - the general contractor, licensed and registered with the state of Oregon and the city of Portland.

3. Permittee is responsible for verifying location and depth of existing branches and verifying that the branch is clear of obstructions before installing the sewer branch. Oregon Law requires you to follow rules adopted by the Oregon Utility Notification Center. Those rules are set forth in OAR 952-001-0010 through 0090. If you have questions or want to obtain a copy of these rules, contact the Center by calling (503)232-1987. You must notify the center at least two business days, but not more than 10 business days, before starting an excavation. The notification number is (503) 246-6699.

4. The sewer branch connection procedures shall be as follows:

   (a) Determine the elevation difference between the ground at the service branch and the lowest floor to be drained.

   (b) Subtract this difference from the depth of the branch indicated by construction as-built records to yield the available fall.

   (c) If the available fall is greater than a minimum of 2.0 feet plus 1/4 inch per foot from the lowest finished floor of the building to the branch, gravity service should be available. Exceptions to the minimum slope requirement on private property may be allowed upon review and approval of the Bureau of Buildings (BOB). The maximum slope in the public right of way, without encasement, is one foot to one foot.

A sewer line with a slope less than the minimum grade and/or proposals to install private pump systems must be approved by BOB and BES.

(d) Expose the end of the branch to verify that as-built information is correct prior to any plumbing installation. Before contacting the Bureau of Maintenance (BOM) for assistance in finding the branch, the exploration for the end of the branch should extend up to 3 feet in all directions (horizontally and vertically).

(e) If the available fall appears to be less than the minimum required or you have excavated to the above limits and still cannot find the end of the branch, contact Development Assistance at 823-7761. Be prepared to adequately shore the excavation and allow access to the building so the City can accurately investigate the situation. If the City's investigation verifies the sewer connection installer's findings, the City will work with the property owner and/or sewer connection installer to resolve the problem.

If gravity service is not available, the City's sole responsibility will be to resolve the problem in a timely fashion, but not on an emergency basis. The sewer connection installer is not entitled to collect or recover from the City any damage, loss or expense incurred due to the branch being unserviceable. The property owner may seek compensation for any such loss incurred through the Bureau of Risk Management claim process.

5. Pipes must be inspected before backfill. Four hours notice is required for inspection in the right-of-way, for inspection on private property you must call to request an inspection prior to 7:30 a.m. on the day the inspection is requested. For a manhole tap, give the right of way inspector 24 hours notice.

6. Work left open overnight shall be protected in accordance with the requirements of the Traffic Engineer and City's Standard Construction Specifications.

7. The City of Portland disclaims all liability or damage to privately-owned sewers in the public right of way and private property.

8. Permittee agrees to protect and hold harmless the City of Portland, its officers, agents, and employees from any and all injury to persons or damage to property that may result from or in any manner arise out of the action of said applicant or permittee making changes, improvements, or alterations pursuant to this permit on or within any public street or other right-of-way in which a public sewer is found.

9. The permittee is responsible for any repair or cost to repair damage to the main sewer or manhole when making a new connection to the city sewer system.

10. For sewer connections where the City is providing a tee, tap or wye, the permittee may be subject to additional service charges by the BOM if the area of excavation does not meet the standards specified in these rules or its supporting regulations.

## SECTION B. RULES SPECIFIC TO SEWER CONNECTIONS IN THE PUBLIC RIGHT OF WAY OR IN PUBLIC SEWER EASEMENTS

1. Allowed pipe materials and minimum pipe sizes for new connections to public sewers in the public right of way are specified in Table No. 1.

| Material | 1 & 2 Family Dwellings | | Commercial, Industrial & Multi-Family | |
|---|---|---|---|---|
| | Min. Size | Sewer Type | Min. Size | Sewer Type |
| Concrete | 6" | Sanitary, Storm | 6" | Sanitary, Storm |
| Cast Iron | 4" | Sanitary, Storm | 6" | Sanitary, Storm |
| PVC | 4" | Sanitary, Storm | 6" | Sanitary Only |
| HDPE | 4" | Sanitary, Storm | 6" | Sanitary, Storm |

Table No. 1.

2. All pipe material shall conform to the standards shown in the City of Portland, Standard Construction Specifications Manual and the City of Portland, Sewer Design Manual.

3. The top of the sewer lateral must be a minimum of 7 feet below the top of the existing or future curb line, or meet the existing branch from the main sewer.

4. The top of the sewer lateral must be a minimum of 2 feet below the street grade at the property line.

5. No bend greater than 1/8 (45 Degrees) is permitted in the right of way.

6. Sewer taps, wyes and branches must be installed perpendicular to the main sewer on uniform line and grade. The connection must allow the sewer flow to merge with the existing sewer flow.

7. Bedding, backfill and compaction of trenches must be made in conformance with the City's Standard Construction Specifications and Title 17 of the Code of the City of Portland.

8. Storm connections to combination sewer lines require approval from BES. For approved combination connections, the storm and sanitary sewer lines may combine at the curb and must leave the property separately to simplify future storm work. Storm and sanitary lines must remain in parallel and at the same grade in the right of way wherever possible.

9. Shoring and trench protection shall be installed as required by OSHA Standards Chapter 437, Rule 1926.650 through 652. and City of Portland Standard Construction Specification Section 204.3.140.

10. The permittee is responsible for de-watering the excavation in accordance with the City of Portland, Standard Construction Specifications Section 204.3.15.

11. Table No. 2 identifies the sizes and types of connections which can be made to various types and sizes of main sewers when a branch or wye is not available.

| | Main Sewer Material | | | | | |
|---|---|---|---|---|---|---|
| Branch Size | VSP | CSP, PVC, HDPE | | | | MH |
| | All Sizes | 8" | 10" | 12" | >12" | N/A |
| 4" | BOM TEE OR TAP | Insert-a-tee | Insert-a-tee | Insert-a-tee | BOM TAP | BOM TAP |
| 6" | | BOM WYE | BOM WYE | Insert-a-tee | | |
| 8" | N/P | N/P | BOM WYE | BOM WYE | | |

VSP = vitreous sewer pipe
CSP = concrete sewer pipe
MH = manhole
Size = main sewer and/or connection size

BOM = Bureau of Maintenance
TEE = factory manufactured tee or wye
TAP = tap installed in field
N/P = not permitted

Insert-a-tee = factory manufactured tap or and approved equivalent (may be installed by contractor)

Table No. 2.

12. A permittee with equipment to make an insert-a-tee connection may tap the main line. The sewer tap size shall not exceed one-half main diameter of the main sewer.

13. The permittee must schedule sewer taps and tee installations to be constructed by the City directly with the BOM a minimum of 1 working day in advance._For locations east of the Willamette River, call 823-1780. For locations west of the Willamette River, call 823-1744. The permittee is responsible for providing and adequately shoring the excavation and furnishing all materials required for the City to install the tap or tee.

14. Written approval must be obtained from BES and the Bureau of Transportation Engineering and Development ( BTED) prior to boring or tunneling in the public right of way. Contact BTED at 823-7002 to initiate the permit process to bore or tunnel under the public right of way.

15. Replacement of street pavements (except concrete) in City areas, must be made by the City, or as approved by the BTED.

16. Written approval must be obtained from BES for inside drop connections to manholes. The following conditions must exist for BES to permit an inside drop.

    a. Miminimum depth for the main sewer must be 15' for and inside drop connection.

    b. No other inside drop structure can exist in the manhole.

    c. A drop support frame must have a minimum clearance of one foot from the outside of the frame to the manhole steps and/or all other connections to the face of the manhole. The drop must not be placed in a location that will obstruct the flow of any other connection to the manhole.

d. The condition of brick manholes must be inspected by the BTED right of way inspector prior to permitting an inside drop to brick manholes.

e. The bolts of the support frame must be installed into the concrete or brick facia of the manhole. Fasteners in grout or mortar are not prohibited.

Contact Development Assistance at 823-7761 for approval of inside drops to public manholes.

17. Each lot shall have individual gravity connections to a public sanitary sewer as approved by BES. Pumped connections require written approval from BES and BOB.

18. Taps to main sewers shall have a minimum separation of 3 feet from the outside diameter to the next lateral. Only one tap is permitted per pipe section for concrete sewer pipe.

19. The City of Portland is responsible for maintenance of inspected sewer laterals to the curb line in the right of way and at the end of the tee or wye in easement areas. Beyond those areas, property owners are responsible for lateral maintenance.

20. Connection of unlike pipe material shall be made with an approved flexible coupling with stainless steel shear bands or an approved equal.

## SECTION C. RULES SPECIFIC TO SEWER CONNECTIONS ON PRIVATE PROPERTY

1. The building sanitary sewer must be the same size as the main building drain (minimum 3" inside diameter) but may be larger if desired.

2. A cleanout fitting is required immediately inside or outside of the building and at the upper terminal of the building's drain system. An additional cleanout is required if the sewer offsets horizontally more than 135 degrees from the previous cleanout or if the sewer line is over 100 feet in length. A cleanout riser on a two-way cleanout is limited to three foot extensions to grade.

3. Fittings permitted to be installed shall be 1/16 bend (22.5 degrees), 1/8 bend (45 degrees), 45 degree wye fittings, or fittings of equivalent sweep.

4. A "test wye" fitting shall be installed at the point of connection to the City installed sewer branch. A test balloon or ball shall be inserted and the entire sewer filled with water to the cleanout for the required inspection.

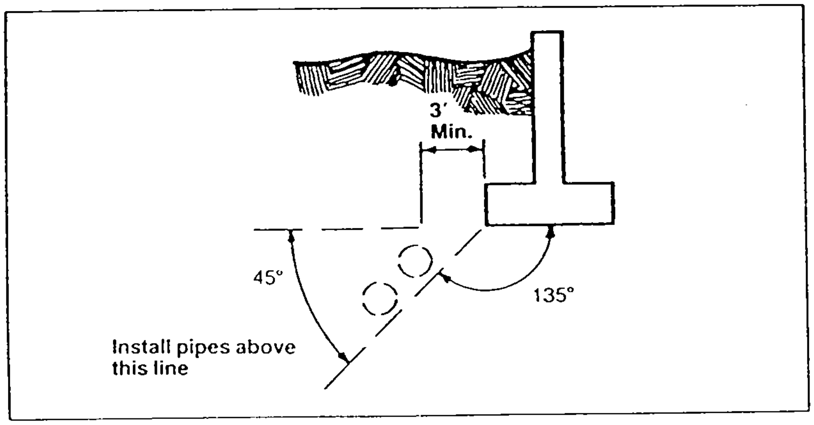
5. Pipes shall be installed in trenches so that it rests on a solid and continuous bearing. Over excavated trenches shall be backfilled and compacted earth, sand, fine gravel or similar granular material. Piping may not be supported on rocks or blocks at any point.

6. Care shall be exercised in backfilling trenches to avoid rocks, broken concrete, frozen chunks and other rubble until the pipe is covered by at least 12 inches of an approved backfill material. Backfill shall be placed evenly on both sides of the pipe and tamped

to retain proper alignment. Clean native soil shall be carefully placed in the trench in 6-inch layers and tamped in place.

7. Trenching installed parallel to footings shall not extend below the 45-degree bearing plane of the bottom edge of a wall or footing. (See Figure 1.)

**Figure No. 1**
**PIPE LOCATION WITH RESPECT TO FOOTINGS**




## SECTION D. OAR 340-71-185 DECOMMISSIONING OF SYSTEMS

(1) The owner shall decommission a system when:

(a) A sewerage system becomes available and the building sewer has been connected there to; or

(b) The source of sewage has been permanently eliminated; or

(c) The system has been operated in violation of OAR 340-71-130(13), unless and until a repair permit and Certificate of Satisfactory Completion are subsequently issued therefor; or

(d) The system has been constructed, installed, altered, or repaired without a required permit authorizing the same, unless and until a permit is subsequently issued therefor; or

(e) The system has been operated or used without a required Certificate of Satisfactory Completion or Authorization Notice authorizing same, unless and until a Certificate of Satisfactory Completion or Authorization Notice is subsequently issued therefor.

(2) Procedures for Decommissioning:

(a) The tank(s), cesspool or seepage pit shall be pumped by a licensed sewage disposal service to remove all septage;

(b) The tank(s), cesspool or seepage pit shall be filled with reject sand, bar run gravel, or other material approved by the Agent, or the container shall be removed and properly disposed;

(3) If, in the judgement of the Agent, it is not reasonably possible or necessary to comply with subsections (2)(a) and (2)(b) of the rule, the Agent may waive either or both of these requirements provided such action does not constitute a menace to public health, welfare or safety.

# Appendix I: Inlets and Inlet Leads

# Appendix I: Inlets and Inlet Leads

*(This Appendix is adapted from the BES 1991 "Sewer Design Manual", section 31, Inlets and Inlet Leads.)*

## 1. GENERAL INFORMATION

Street inlets/catch basins, field inlets and their outlet pipes (i.e. leads) collect stormwater from appropriate locations within a right-of-way and discharge this runoff into a storm sewer or another suitable facility designed to receive this water. Inlets are generally located adjacent to the curb face in the gutter section of improved streets and prevent street flooding and to protect both traffic flow and pedestrians.

It is the responsibility of the designer to determine the suitable locations to collect and dispose of this runoff, select the appropriate type and size of inlet, and determine the proper lead size, slope and location. Once the design is completed, final approval from the Portland Office of Transportation (PDOT) must be obtained.

## 2. INLET AND CATCH BASIN LOCATIONS

Inlets must be placed at all street low points, at intersections, at points where change to the street configuration directs water flow across the travel lane(s) or sidewalk and at intervals on continuous grades to control the width of runoff carried in a street gutter. Unless otherwise approved by PDOT, inlets shall be designed and spaced to limit the width (i.e. spread) of gutter flow to 2 feet or less into the travel lane. If bike lanes are present, then that space can be included when calculating allowable gutter flow width. (See CHARTS 25 and 26, STREET GEOMETRICS, at the end of this appendix.)

Field inlets are often used to collect water from ditches, creeks and other side streams in order to convey water and runoff safely under a street to prevent overflow and street damage or a public safety hazard. (See Appendix J: Culverts, Sewer and Drainage Facilities Design Manual (SDFDM))

## 3. GUTTER FLOW QUANTITY

Use the Rational Method to estimate the quantity of gutter flow. The design storm frequency and the coefficient of runoff shall be the same as those selected for design of the storm sewer system. The contributing drainage basin is the entire area that drains directly to an inlet. For an inlet located in an improved right-of-way the Time of Concentration ($T_c$) shall be 5 minutes (maximum) unless it can be shown that the time to reach the inlet is greater than 5-minutes. (Refer to Chapter 6, Hydrologic Analysis in the SDFDM).

The quantity of gutter flow for a given width and flow depth, street cross slope and gutter longitudinal slope is calculated using a modification of Manning's equation. The modified equation is shown in CHART 1, STANDARD EQUATIONS (see end of this appendix). For a paved gutter surface in good condition use a Manning coefficient of roughness ($n_{gutter}$) equal to 0.018. CHART 30, FLOW IN TRIANGULAR GUTTER SECTIONS, (see end of this appendix), may also be used to determine the width, depth and quantity of flow.

## 4. INLET AND CATCH BASIN CAPACITY

The capacity of an inlet depends upon the type and size; the street cross slope; whether it is located, in a street sag section (i.e. sump) or on a continuous grade; the allowed depth and width of gutter flow and the velocity of the approaching flow when following a continuous grade. Clogging of the grate with debris reduces the capacity of an inlet. Therefore, for design purposes, the City requires designers to reduce the theoretical capacity of gutter inlets grates by 50% and a curb/gutter inlet grate by 35% to compensate for partial clogging of the grate with debris. CHART 28, INLET CAPACITY - Sag Locations (see end of this appendix), shows capacities for various water depths for standard inlets in sags. FORMS 3 and 4, with the accompanying PROCEDURES, and CHARTS 29 through 32 (all at end of this appendix) may be used to determine the capacities of inlets on a continuous grade.

The inlet design flow must equal or exceed the gutter design flow. Where practical, each inlet should collect all of the upstream gutter flow. Any bypassing flow must be compensated for in the capacity of downstream inlet(s). In locations where overflow may cause significant damage or pose a safety hazard, the inlet design flow must be increased to provide adequate capacity for any stormwater that may bypass uphill inlets or otherwise reach the inlet resulting from a 100-year storm.

## 5. INLET LEAD SIZE, SLOPE AND LOCATION

The minimum pipe diameter for all inlet leads is 10 inches. The minimum slope is 2%. Inlet leads shall be designed without vertical or horizontal bends whenever possible. If bends are needed, keep to a minimum of 1/16th bend (22.5 degrees).

Each inlet lead must connect directly to a storm sewer, culvert, combined sewer, or to an approved discharge point. When connected to a sewer or culvert less than 24 inches in diameter, the connection must be made at a manhole, as shown on Standard Plan 4-06-3. Inlets shall not be interconnected except where two Standard Plan 4-30 inlets are required for adequate capacity and interception. In this case, two inlets may be connected end to end within a common gutter at a spacing not to exceed 10-feet. In sags, interconnect three inlets together with either inlet from the low point being 0.1 feet higher in elevation as a safety factor in case of plugging. The minimum pipe diameter for leads leaving these connected inlets shall be 12-inches.

Inlet leads must be located in accordance with the requirements for sewers. (Also see Chapter 3, General Design Requirements in the SDFDM. Leads will normally be placed at 90 degrees to a connecting sewer to minimize conflict during excavation with other underground utilities. Where this is not practical, such as at intersections, inlets leads shall be placed on the straightest and most direct practical alignment. Placing leads at an angle across the street as a means of shortening the pipe is not allowed.

## 6. INLET AND CATCH BASIN TYPE AND SIZE

There are several street inlet and catch basin designs shown in the Oregon Standard Drawings. These standards are suitable for most applications. The choice of which inlet or catch basin to use depends upon several factors: quantity of flow; velocity of flow; sag or continuous grade; expected amount of debris; etc. The typical application of each type of inlet or catch basin is described in the following paragraphs:

RD364, G-1 — A gutter inlet, suitable for small low velocity flows in areas with a minor amount of expected debris. Use in bike lanes and where there is not full height curb. Similar to City Standard Plan 4-30.

RD364, G-2 — A medium size gutter inlet, suitable for moderate, low velocity flows in areas with a minor amount of expected debris. They cannot be used where the downstream system is less than 10 inches in diameter. Use where there is not full height curb. Not suitable for bike lanes without approval from PDOT. Similar to City Standard Plan 4-31-2.

RD366, CG-1 — A curb/gutter inlet, suitable for larger flows in sags and moderate, low velocity flows on slopes and in areas with a larger amount of expected debris. They cannot be used at driveways, where there is not a full height curb or where the downstream system is less than 10 inches in diameter. Use in bike lanes and where there is full height curb. Similar to City Standard Plan 4-32-3.

RD366, CG-2 — A double curb/gutter inlet, suitable for larger flows in sags and large, moderate velocity flows on slopes and in areas with a moderate amount of expected debris. They cannot be used at driveways, where there is not full height curb or where the downstream system is less than 10 inches in diameter. Not suitable for bike lanes without approval from PDOT. Similar to City Standard Plan 4-32-4.

RD372, CG-3 — A medium size curb inlet, suitable for larger flows in sags and low velocity flows on slopes and in areas with a larger amount of expected debris. They cannot be used at driveways or where the downstream system is less than 10 inches in diameter. Not suitable for bike lanes without approval from PDOT. Similar to City Standard Plan 4-32-1.

RD370, D — A large sloped inlet used to capture flow in a ditch and redirect into a pipe. Use two type 1 grates instead of one grate specified in drawing to make it easier to remove the grate for maintenance. Similar to City Standard Plan 4-33-1.

RD364,G-2MA — A large drainage area inlet, typically placed in the low spot of a vegetated area. Use two type 1 grates instead of one grate specified in drawing to make it easier to remove grate for maintenance. Consider installing cross bars if bikes may use area.

RD374 — A catch basin to drain areas behind sidewalks. Drawing needs to be modified to comply with Portland Plumbing Code when installed on private property.

In general, gutter inlets are more suitable for use on slopes and curb/gutter inlets for use in sags. Gutter inlets have a greater tendency to clog and curb inlets are inefficient for high velocity flows. Large or high velocity flows may require multiple inlets or a special inlet design. All grates must be designed using bars in both directions or have bicycle protection bars installed when using bars in one direction.

## References

Reference 13 in the following charts is from:

US Dept. of Transportation, Federal Highway Administration (FHWA), Washington, D.C.

13. DRAINAGE OF HIGHWAY PAVEMENTS (HEC 12) 1984,
    FHWA # TS-84-202, NTIS # PB84-215003 / AS.

## STANDARD EQUATIONS

**SEWER CURVE RADIUS :** ( Deflected Straight Pipe ) All units are in feet.

$R = DL / G$ = Radius for a given diameter, laying length and gap

$R_{1/4} = 48\ DL$ = Radius that will produce a 1/4" ( 0.02083' ) gap

$G = DL / R$ = Gap that will be produced for a given radius, laying length and diameter

- D  Outside diameter of the pipe barrel at the joint (spigot)
- L  Laying length of one section of pipe
- G  Joint gap or opening at the outside edge of the pipe barrel when the pipe is in the deflected position
- R  Radius of the curve on the pipe centerline

**MANNING'S EQUATION:** ( Open Channel Flow )

$$Q = \frac{1.486}{n} AR^{2/3} S^{1/2}$$

$$V = \frac{1.486}{n} R^{2/3} S^{1/2}$$

Manning's Eq. for circular pipe flowing full

$$\left\{ \begin{array}{l} Q = \frac{0.463}{n} D^{8/3} S^{1/2} \\ V = \frac{0.590}{n} D^{2/3} S^{1/2} \end{array} \right.$$

- Q  Quantity of flow, cubic feet per second
- V  Velocity of flow, feet per second
- n  Manning's coefficient of roughness ( see **CHART 7** )
- A  Cross-sectional area, square feet
- R  Hydraulic radius ( area of flow divided by wetted perimeter ), feet
- S  Slope of the pipe or energy line, feet per foot
- D  Diameter of pipe, feet

**RATIONAL METHOD:** ( Stormwater Design Flows )

$Q = CIA$ ( Max. drainage area = 100 acres ---- Max. time = 60 minutes)

- Q  Quantity of runoff, cubic feet per second
- C  Coefficient of runoff ( ratio of runoff to rainfall ), percent
- I  Intensity of rainfall, inches per hour
- A  Area of tributary drainage basin, acres

**GUTTER FLOW CAPACITY:** ( Manning's Equation Modified )

$$Q = 0.56\ \frac{1/S_x}{n} S^{0.5}\ d^{2.67} \quad \text{or} \quad Q = \frac{0.56}{n} S_x^{1.67} S^{0.5}\ T^{2.67} \qquad V = \frac{1.12}{n} S^{0.5}\ S_x^{0.67}\ T^{0.67}$$

- Q  Quantity of flow, cubic feet per second
- $S_x$  Street cross slope, feet per foot
- S  Street longitudinal slope, feet per foot
- n  Manning's coefficient of roughness for the gutter, ( normally 0.018 )
- d  Depth of flow at the curb, feet
- T  Total width of flow in the gutter, Feet

**TIME OF CONCENTRATION:** ( Overland Stormwater Flow )

$T_t = L / 60V$ ( for conversion of velocity to travel time )

$T_c = T_{t1} + T_{t2} + \ldots\ T_{tm}$

$$T_t = \frac{0.42\ (\ nL\ )^{0.8}}{1.58\ (\ S\ )^{0.4}}$$ ( Manning's kinematic solution for sheet flow less than 300 feet )

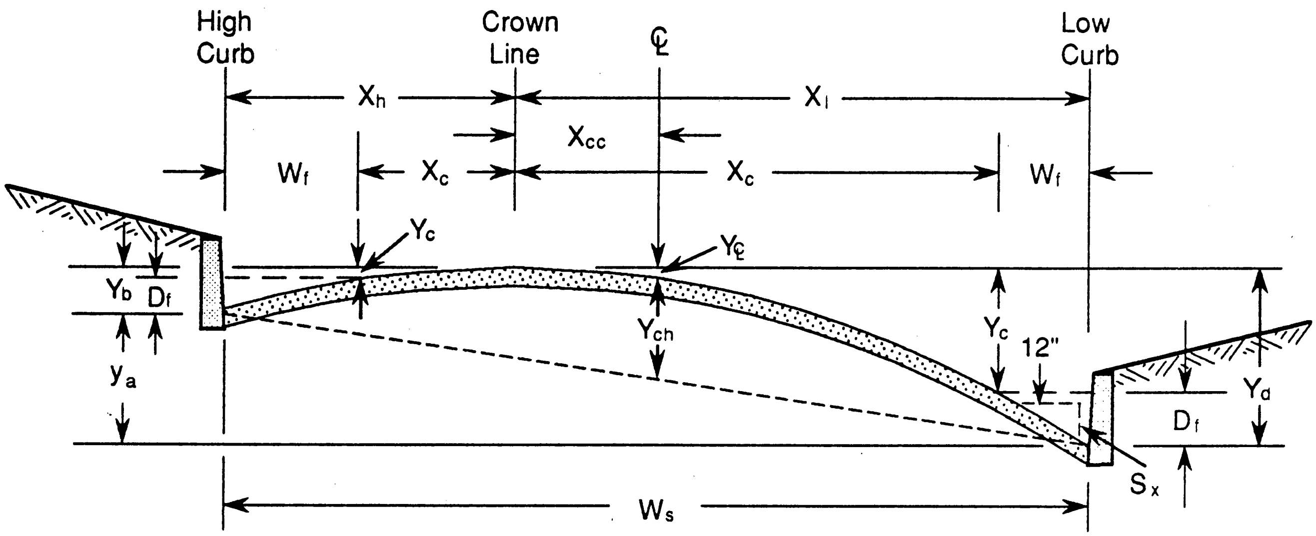
$V = 16.1345\ (\ S\ )^{0.5}$ ( Unpaved surfaces )

$V = 20.3282\ (\ S\ )^{0.5}$ ( Paved surfaces )

} ( Shallow concentrated flow for slopes less than 0.005 ft / ft. For steeper slopes see **CHART 9** )

- $T_t$  Travel time, minutes
- L  Flow length, feet
- V  Average velocity of flow, feet per second
- 60  Conversion factor from seconds to minutes
- $T_c$  Total time of concentration, minutes ( minimum $T_c$ = 5.0 minutes )
- n  Manning's roughness coefficient for various surfaces, ( see **CHART 10** )
- S  Slope of the hydraulic grade line ( land or watercourse slope ), feet per foot
- 1.58  A factor derived from Ref. No. 8 ( $P_2$ , from 2 year, 24 hour precipitation chart, for the Portland, Oregon area [ $P_2^{0.5} = 2.5^{0.5} = 1.58$ ] )

## STREET GEOMETRICS
### PARABOLIC CROWN




All dimensions are in feet.

The gutter cross slope ( $S_x$ ) and the street longitudinal slope ( S ) are in feet per foot.

$W_f$ = the width of flow, which may be given or may be determined by other factors. For example; depth of gutter flow, crown height, curb height.

$W_s$, $y_a$, $Y_{ch}$ and S are normally given.

$X_c$ = the distance from the crown to any point on either side of the crown.

$Y_c$ = the drop from the crown at any distance ($X_c$) from the crown.

K = a constant for any given street width ($W_s$) and crown height ( $Y_{ch}$ ).

$X_{cc} = \frac{Y_a W_s}{8 Y_{ch}}$ = feet; $X_l = X_{cc} + \frac{W_s}{2}$ = feet; $X_h = W_s - X_l$ = feet

$Y_{℄} = \frac{Y_a^2}{16 Y_{ch}}$ = feet; $Y_d = \frac{Y_a}{2} + Y_{ch} + Y_{℄}$ = feet; $Y_b = Y_d - Y_a$ = feet

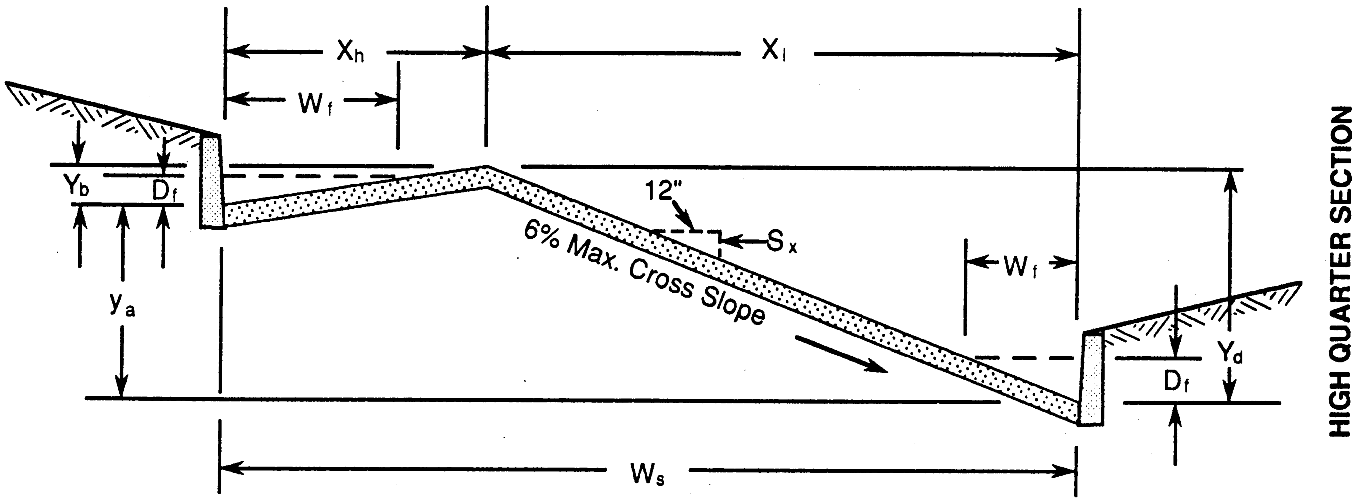
$K = Y_{ch} \div \left(\frac{W_s}{2}\right)^2$ or $K = \frac{Y_d}{X_l^2}$

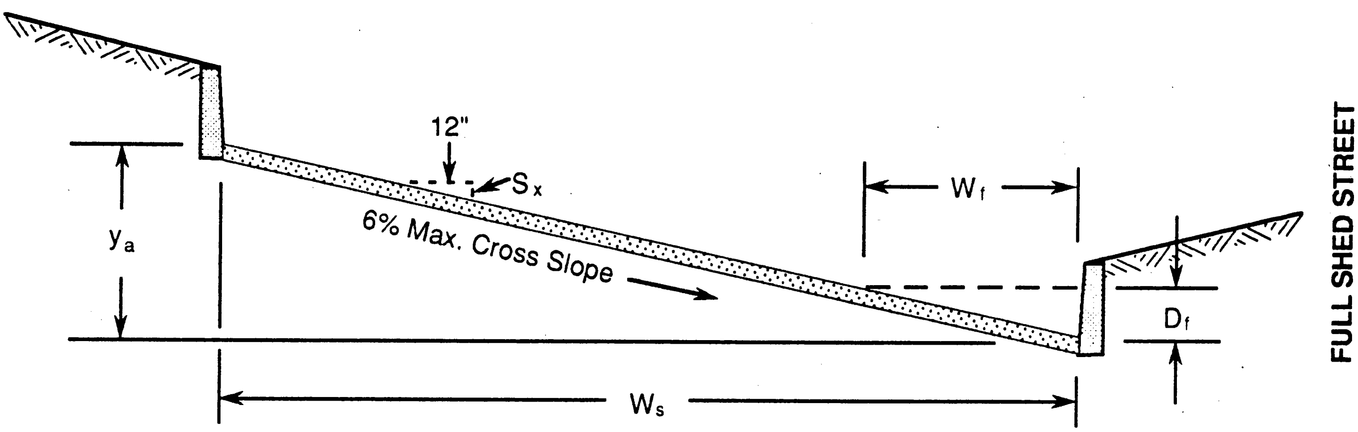
$Y_c = K X_c^2$ = feet or $Y_c = \frac{Y_d X_c^2}{X_l^2}$ = feet

$D_f = Y_b - Y_c$ ( high gutter ) = feet, or $D_f = Y_d - Y_c$ ( low gutter ) = feet

( if $D_f$ given ) $W_f = \frac{D_f}{S_x}$ = feet or ( if $W_f$ given ) $S_x = \frac{D_f}{W_f}$ = feet per foot

## STREET GEOMETRICS




All dimensions are in feet.

The gutter cross slope ( $S_x$ ) and the street longitudinal slope ( S ) are in feet per foot.

$W_f$ = the width of flow, which may be given or may be determined by other factors. For example; depth of gutter flow, crown height, curb height.

Constants: $X_h$ = 10 feet; $Y_b$ = 2 inches = 0.1667 feet.

$W_s$ , $y_a$ and S are normally given.

$S_x = \frac{Y_b}{X_h}$ ( high gutter ) = feet per foot = constant of 0.0167 ( High Quarter Section )

$S_x = \frac{Y_d}{X_l}$ ( low gutter ) = feet per foot ( High Quarter Section )

$S_x = \frac{y_a}{W_s}$ = feet per foot ( Full Shed Street )

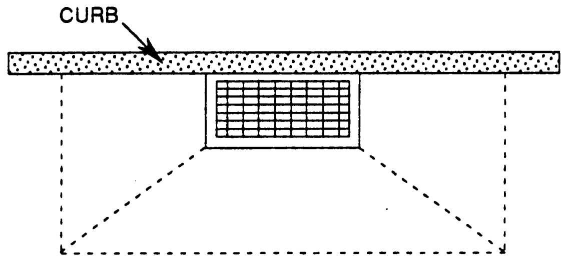
$X_l = W_s - X_h$ = feet

( if $W_f$ given ) $D_f = S_x W_f$ = feet

( if $D_f$ given ) $W_f = \frac{D_f}{S_x}$ = feet

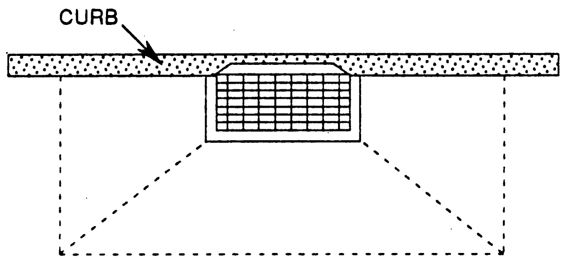
# INLET DIMENSIONS & CRITERIA

## 4-30 INLET
(ONE 4-39 GRATE)



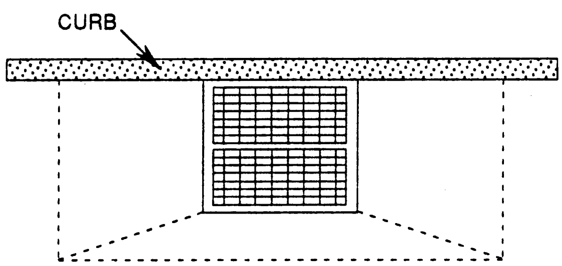

| | |
|---|---|
| GRATE LENGTH | 2.67 feet |
| GRATE WIDTH | 1.12 feet |
| GRATE OPEN AREA | 1.93 sq. ft. |
| 3 SIDE PERIMETER | 4.92 feet |
| DEPRESSION WIDTH | 4.00 feet |
| DEPRESSION AT CURB | 0.167 feet |
| SPLASH-OVER VELOCITY, Vo | 5.7 ft. per sec. |
| REDUCTION FOR CLOGGING | 50% |
| MIN. LEAD DIA. | 8 inches |
| MIN. LEAD SLOPE | 2.00 percent |

## 4-32-3 INLET
(ONE 4-39 GRATE W/ CURB OPENING)



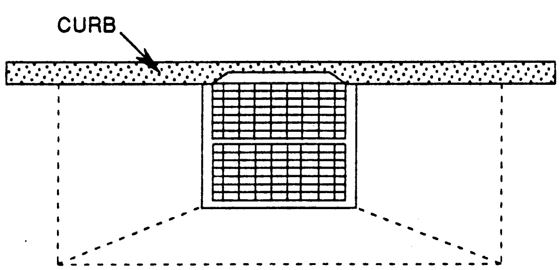

| | |
|---|---|
| GRATE LENGTH | 2.67 feet |
| GRATE WIDTH | 1.12 feet |
| GRATE OPEN AREA | 1.93 sq. ft. |
| 3 SIDE PERIMETER | 4.92 feet |
| DEPRESSION WIDTH | 4.00 feet |
| DEPRESSION AT CURB | 0.167 feet |
| SPLASH-OVER VELOCITY, Vo | 5.7 ft. per sec. |
| OPENING LENGTH | 2.35 feet |
| OPENING HEIGHT | 0.20 feet |
| OPENING AREA | 0.47 sq. ft. |
| REDUCTION FOR CLOGGING | 35% |
| MIN. LEAD DIA. | 10 inches |
| MIN. LEAD SLOPE | 2.00 percent |

## 4-31-2 INLET & 4-31-3 CATCH BASIN
(TWO 4-39 GRATES)



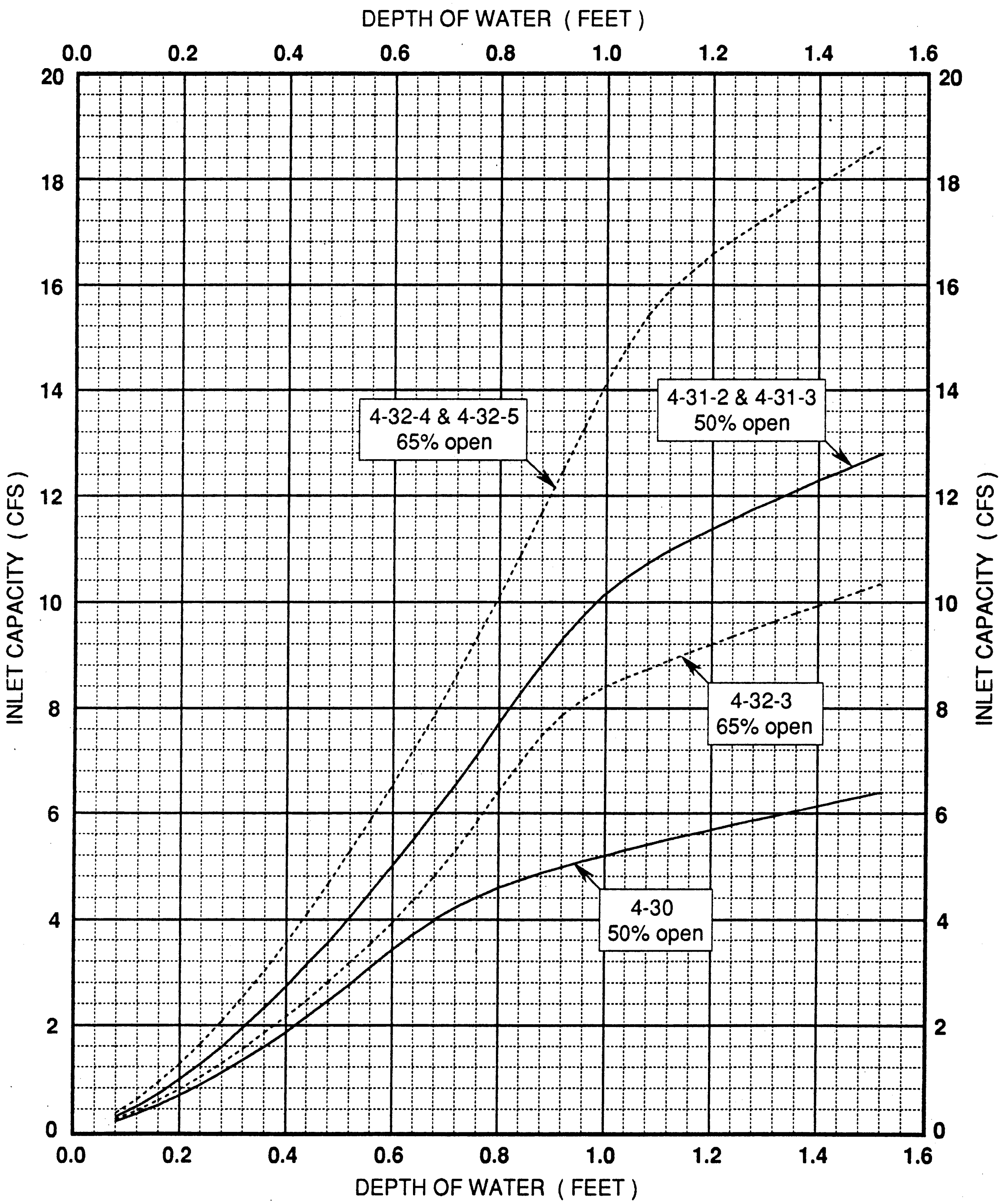

| | |
|---|---|
| GRATE LENGTH | 2.67 feet |
| GRATE WIDTH | 2.25 feet |
| GRATE OPEN AREA | 3.86 sq. ft. |
| 3 SIDE PERIMETER | 7.17 feet |
| DEPRESSION WIDTH | 4.00 feet |
| DEPRESSION AT CURB | 0.167 feet |
| SPLASH-OVER VELOCITY, Vo | 5.7 ft. per sec. |
| REDUCTION FOR CLOGGING | 50% |
| MIN. LEAD DIA. | 10 inches |
| MIN. LEAD SLOPE | 2.00 percent |

## 4-32-4 INLET & 4-32-5 CATCH BASIN
(TWO 4-39 GRATES W/ CURB OPENING)




| | |
|---|---|
| GRATE LENGTH | 2.67 feet |
| GRATE WIDTH | 2.25 feet |
| GRATE OPEN AREA | 3.86 sq. ft. |
| 3 SIDE PERIMETER | 7.17 feet |
| DEPRESSION WIDTH | 4.00 feet |
| DEPRESSION AT CURB | 0.167 feet |
| SPLASH OVER VELOCITY, Vo | 5.7 ft. per sec. |
| OPENING LENGTH | 2.35 feet |
| OPENING HEIGHT | 0.20 feet |
| OPENING AREA | 0.47 sq. ft. |
| REDUCTION FOR CLOGGING | 35% |
| MIN. LEAD DIA. | 10 inches |
| MIN. LEAD SLOPE | 2.00 % |

# INLET CAPACITY
## SAG LOCATIONS



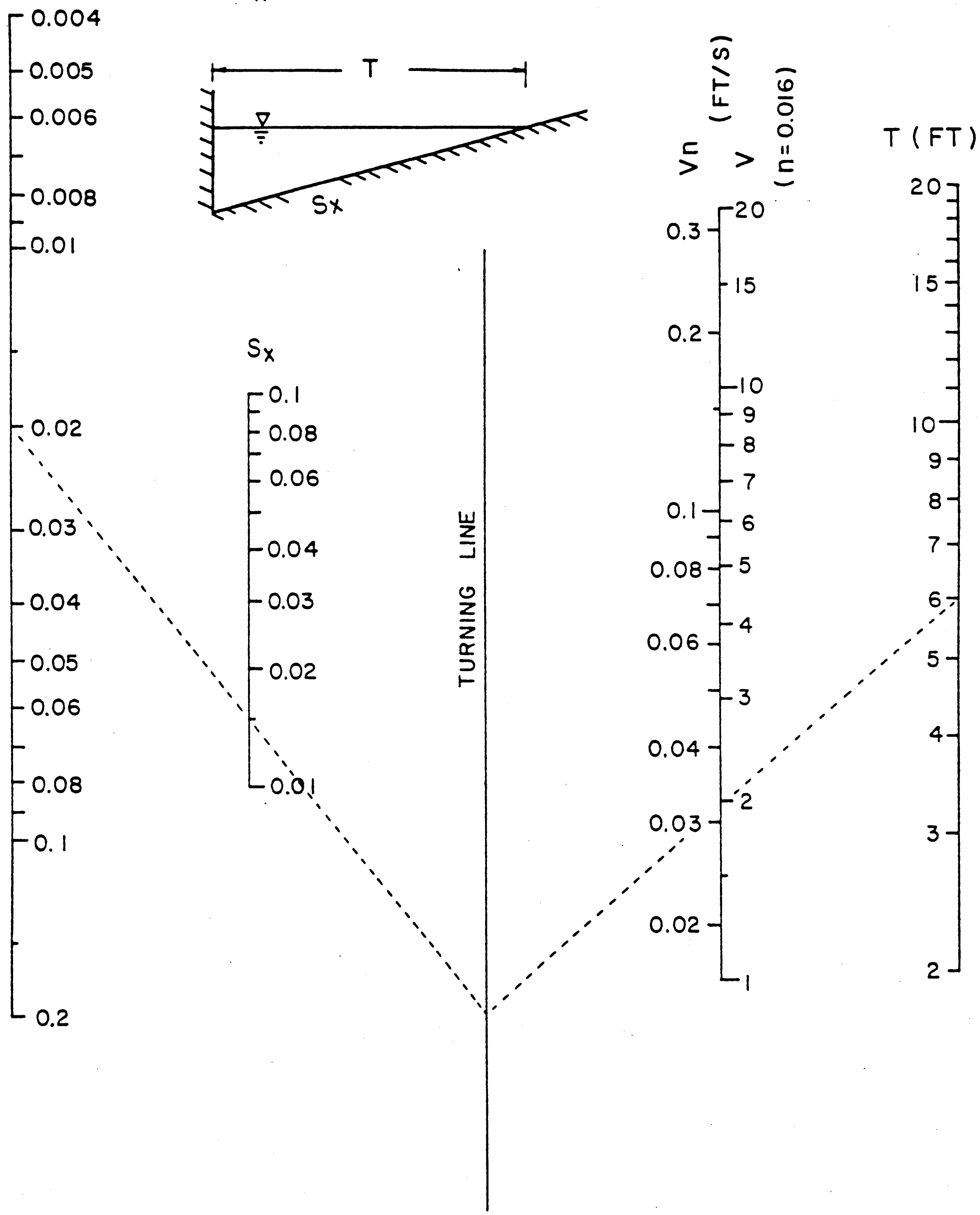

Plotted from Ref. No. 13;

Equation 17, Page 69, Capacity of grate inlets operating in weir flow
Equation 18, Page 69, Capacity of grate inlets operating in orifice flow
Equation 22, Page 76, Capacity of curb inlets with other than vertical faces operating in orifice flow
Capacities curves have been adjusted to reflect the transition from weir flow to orifice flow.

See Ref. No. 13 for the equations and their applications.

## VELOCITY IN TRIANGULAR GUTTER SECTIONS

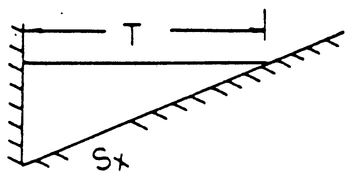
$$V = \frac{1.12}{n} S^{0.5} S_x^{0.67} T^{0.67}$$




EXAMPLE: Given; S = 0.02 ft / ft, Sx = 0.015 ft / ft, T = 6.0 feet, n = 0.016
Find; Vn = 0.032 fps, V = 1.95 fps

From Ref. No. 13, Chart 2, Page 18.

# FLOW IN TRIANGULAR GUTTER SECTIONS




$$Q = \frac{0.56}{n} S_x^{1.67} S^{0.5} T^{2.67}$$

EXAMPLE: GIVEN:

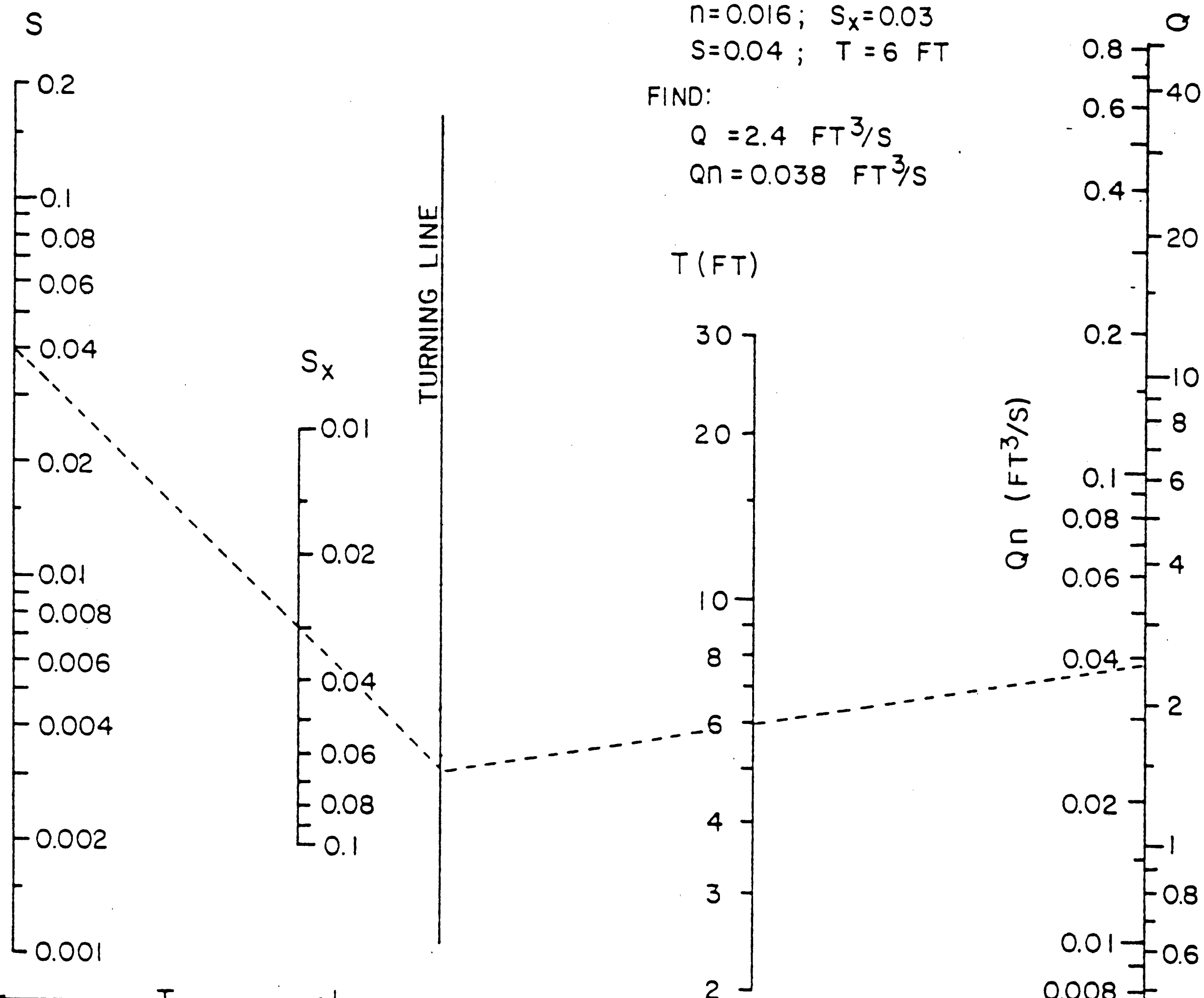
$n = 0.016$; $S_x = 0.03$

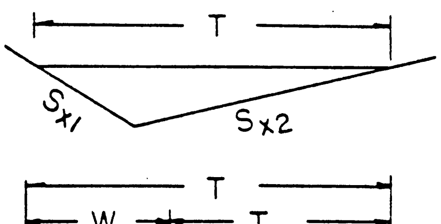
$S = 0.04$; $T = 6$ FT

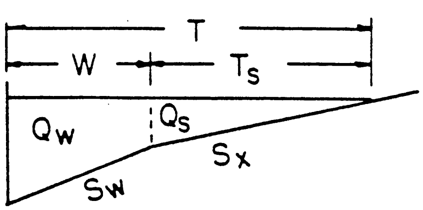
FIND:

$Q = 2.4$ $FT^3/S$

$Qn = 0.038$ $FT^3/S$



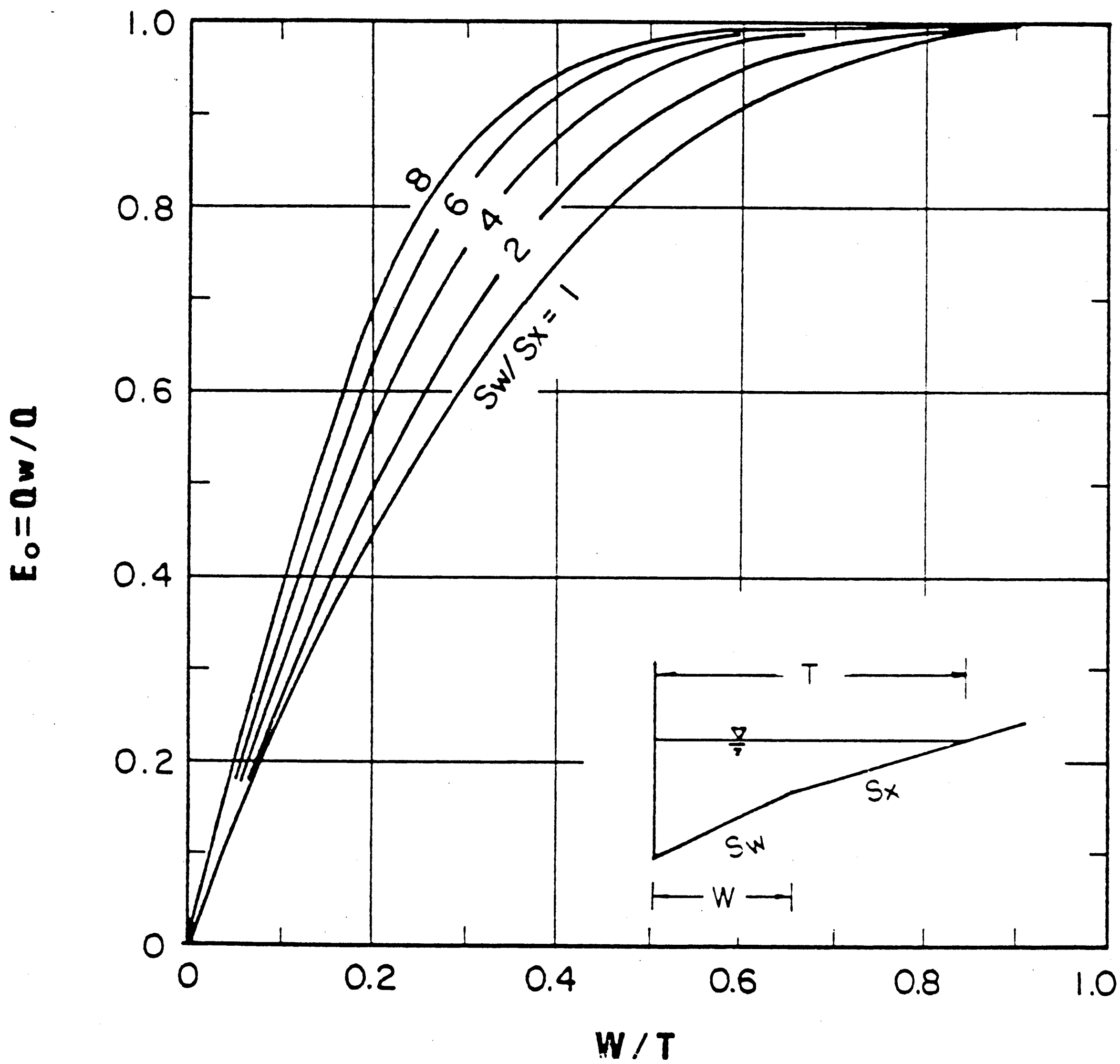




1) For V-Shape, use the nomograph with $S_x = S_{x1} S_{x2} / (S_{x1} + S_{x2})$

2) To determine discharge in a gutter with composite cross slopes, find $Q_s$ using $T_s$ and $S_x$. Then, use CHART 31 to find $E_o$. The total discharge is $Q = Q_s / (1 - E_o)$ and $Q_w = Q - Q_s$.

From Ref. No. 13, Chart 3, Page 23.

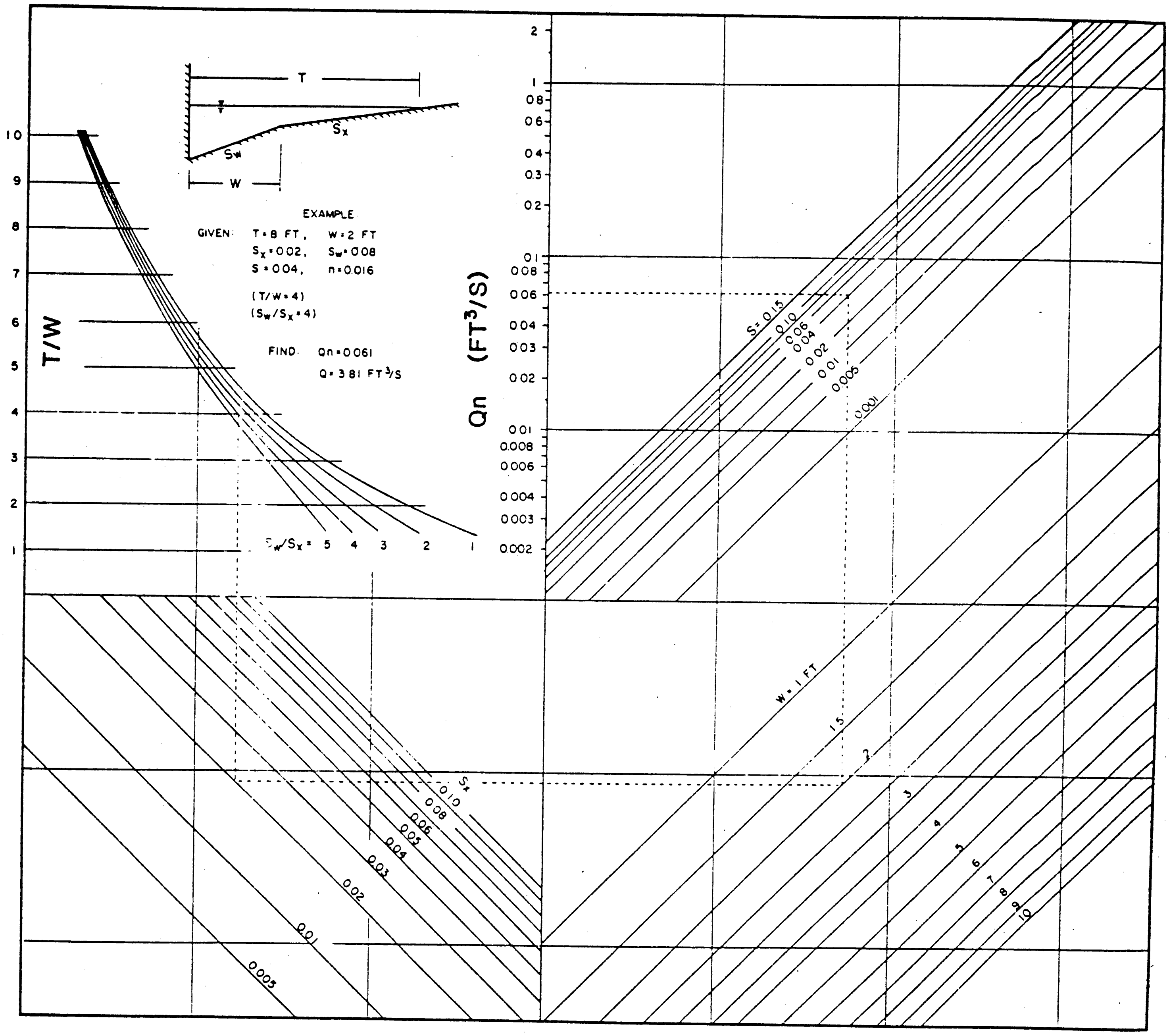
## RATIO OF FRONTAL FLOW TO TOTAL GUTTER FLOW




From Ref. No. 13, Chart 4, Page 25.

BES August 7, 1990

# FLOW IN COMPOSITE GUTTER SECTIONS




**CAUTION:** Use of this chart requires extreme care to obtain accurate results!

**TO DETERMINE T FROM A KNOWN Q:**

Given: Q = 3.81 cfs
n = 0.016
W = 2 ft
$S_x$ = 0.02
S = 0.04
$S_w$ = 0.08

Find: Qn = 0.061
$S_w/S_x$ = 4
T/W = 4
T = (T/W) x W
T = 4x2 = 8 ft

From Ref. No. 13, Chart 5, Page 27.

BES August 7, 1990

# INLET DESIGN FORM
## CONTINUOUS GRADE - UNIFORM CROSS SLOPE

Project No. __________ Designed by __________ Date __________ Checked by __________ Date __________
Project name: ____________________

| Inlet standard plan No. → | | | | | | | | ← Inlet standard plan No. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Inlet location or No. → | | | | | | | | ← Inlet location or No. | | |
| GRATE INLETS | | | | | | | | CURB INLETS | | |
| STEP | SYMBOL | UNIT | | | | | | UNIT | SYMBOL | STEP |
| 1 | W | ft | | | | | | ft | W | 1 |
| 1 | L | ft | | | | | | ft | L | 1 |
| 1 | a | ft | | | | | | ft | a | 1 |
| 2 | n | coeff | | | | | | coeff | n | 2 |
| 3 | S | ft / ft | | | | | | ft / ft | S | 3 |
| 3 | $S_x$ | ft / ft | | | | | | ft / ft | $S_x$ | 3 |
| 4 | T | ft | | | | | | const. | K | 4 |
| 5 | Q n | cfs | | | | | | ft | T | 5 |
| 6 | Q | cfs | | | | | | cfs | Q n | 6 |
| 7 | $T_s$ | ft | | | | | | cfs | Q | 7 |
| 8 | $Q_s$ n | cfs | | | | | | ft | d | 8 |
| 9 | $Q_s$ | cfs | | | | | | ft | $L_T$ | 9 |
| 10 | $Q_w$ | cfs | | | | | | ratio | $L/L_T$ | 10 |
| 11 | $E_o$ | ratio | | | | | | ratio | E | 11 |
| 12 | d | ft | | | | | | cfs | $Q_i$ | 12 |
| 13 | A | sq ft | | | | | | cfs | $Q_b$ | 13 |
| 14 | V | fps | | | | | | | | |
| 15 | $V_o$ | fps | | | | | | | | |
| 16 | $R_f$ | ratio | | | | | | | | |
| 17 | $R_s$ | ratio | | | | | | | | |
| 18 | E | ratio | | | | | | | | |
| 19 | $Q_i$ | cfs | | | | | | | | |
| 20 | $Q_b$ | cfs | | | | | | | | |

BES August 7, 1990

## GRATE INLET CAPACITY PROCEDURES
### CONTINUOUS GRADE - UNIFORM CROSS SLOPE

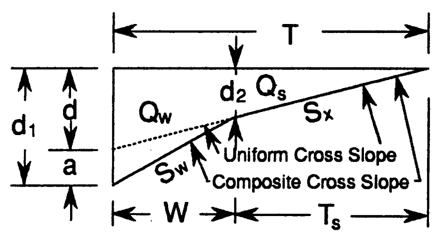
Using the **INLET DESIGN FORM ( FORM 3 )**:

1. Note inlet Standard Plan No., dimensions, ( W, L & a ) and location or No.
2. Note Manning's coefficient of roughness, n ( normally 0.018 ).
3. Determine and note the street geometrics ( cross slope, $S_x$ ; longitudinal slope, S ) using the street design and / or survey ( see **STREET GEOMETRICS, CHARTS 25 & 26** )

Determine the following from calculations or noted charts:

* 4. T ( Use maximum allowable width of flow or other known width. )
* 5. Q n ( **CHART 30** )
* 6. $Q = Qn/n$
7. $T_s = T - W$
8. $Q_s n$ ( **CHART 30** )
9. $Q_s = Q_s n / n$
10. $Q_w = Q - Q_s$
11. $E_o = Q_w / Q$ (or **CHART 31** @ $S_w/S_x = 1$)
12. $d = TS_x$
13. $A = (dT) / 2$
14. $V = Q / A$
15. $V_o$ ( **CHART 27** )
16. $R_f = 1 - 0.09\ (V_o - V)$ if $V > V_o$
    $R_f = 1$ if $V \le V_o$
17. $R_s = 1 \Big/ \left(1 + \dfrac{0.15\ V^{1.8}}{S_x\ L^{2.3}}\right)$
18. $E = R_f E_o + R_s (1 - E_o)$
19. $Q_i = EQ$
20. $Q_b = Q - Q_i$

* To determine T from a known Q, reverse the order of steps 4 through 6




- a gutter depression, inches
- A cross-sectional area of flow, sq ft
- d depth of flow at the curb
- E efficiency of a grate ( interception efficiency of an inlet )
- $E_o$ ratio of frontal flow to total gutter flow
- L length of the grate, ft
- n Manning's coefficient of roughness
- Q total gutter flow, cfs
- $Q_b$ the portion of total gutter flow which is not intercepted by an inlet ( bypass or carryover flow ), cfs
- $Q_i$ the portion of total gutter flow which is intercepted by an inlet ( intercepted flow ), cfs
- $Q_s$ side flow rate
- $Q_w$ flow in width W, cfs
- $R_f$ ratio of frontal flow intercepted to total frontal flow ( frontal flow interception efficiency )
- $R_s$ ratio of side flow intercepted to total side flow ( side flow interception efficiency )
- S pavement longitudinal slope, ft / ft
- $S_x$ pavement cross slope, ft / ft
- T total spread of water in the gutter, ft
- $T_s$ spread of water outside depressed gutter
- V velocity of flow in the gutter, fps
- $V_o$ gutter velocity where splash-over first occurs over a grate, fps
- W width of depressed inlet, ft

## CURB INLET CAPACITY PROCEDURES
### CONTINUOUS GRADE - UNIFORM CROSS SLOPE

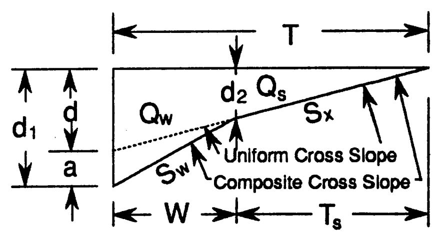
Using the **INLET DESIGN FORM ( FORM 3 )**:

1. Note inlet Standard Plan No., dimensions, ( W, L & a ) and location or inlet No.
2. Note Manning's coefficient of roughness, n ( normally 0.018 ).
3. Determine and note the street geometrics ( cross slope, $S_x$ ; longitudinal slope, S ) using the street design and / or survey ( see **STREET GEOMETRICS, CHARTS 25 & 26** )

Determine the following from known quantities, calculations or noted charts:

4. $K = 0.6$ ( 0.076 if in S. I. )
* 5. T ( Use maximum allowable width of flow or other known width )
* 6. Q n ( From **CHART 30** )
* 7. $Q = Qn / n$
8. $d = TS_x$
9. $L_T = KQ^{0.42} S^{0.3} (1 / nS_x)^{0.6}$
10. $L / L_T$
11. $E = 1 - (1 - L / L_T)^{1.8}$
12. $Q_i = EQ$
13. $Q_b = Q - Q_i$

* To determine T from a known Q, reverse the order of steps 5 through 7.




a gutter depression, inches
d depth of flow at the curb
E efficiency of a grate ( interception efficiency of an inlet )
K constant (0.6 or 0.076 if in S. I. )
L length of the grate, ft
n Manning's coefficient of roughness
Q total gutter flow, cfs
$Q_b$ the portion of total gutter flow which is not intercepted by an inlet ( bypass or carryover flow ), cfs
$Q_i$ the portion of total gutter flow which is intercepted by an inlet ( intercepted flow ), cfs
S pavement longitudinal slope, ft / ft
$S_w$ depressed gutter cross slope
$S_x$ pavement cross slope, ft / ft
T total spread of water in the gutter, ft
W width of depressed gutter or grate, ft

## INLET DESIGN FORM
### CONTINUOUS GRADE - COMPOSITE CROSS SLOPE

Project No. __________ Designed by __________ Date __________ Checked by __________ Date __________
Project name: ____________________________________________

| Inlet standard plan No. → | | | | | | | | ← Inlet standard plan No. | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Inlet location or No. → | | | | | | | | ← Inlet location or No. | | |
| GRATE INLETS | | | | | | | | CURB INLETS | | |
| STEP | SYMBOL | UNIT | | | | | | UNIT | SYMBOL | STEP |
| 1 | W | ft | | | | | | ft | W | 1 |
| 1 | L | ft | | | | | | ft | L | 1 |
| 1 | a | ft | | | | | | ft | a | 1 |
| 2 | n | coeff | | | | | | coeff | n | 2 |
| 3 | S | ft / ft | | | | | | ft / ft | S | 3 |
| 3 | $S_x$ | ft / ft | | | | | | ft / ft | $S_x$ | 3 |
| 4 | $S_w$ | ft / ft | | | | | | ft / ft | $S'_w$ | 4 |
| 5 | $S_w/S_x$ | ratio | | | | | | ft / ft | $S_w$ | 5 |
| 6 | T | ft | | | | | | ratio | $S_w/S_x$ | 6 |
| 7 | $T_s$ | ft | | | | | | const. | K | 7 |
| 8 | $Q_s n$ | cfs | | | | | | ft | T | 8 |
| 9 | $Q_s$ | cfs | | | | | | ratio | T / W | 9 |
| 10 | W / T | ratio | | | | | | cfs | Qn | 10 |
| 11 | $E_o$ | ratio | | | | | | cfs | Q | 11 |
| 12 | Q | cfs | | | | | | ratio | W / T | 12 |
| 13 | $Q_w$ | cfs | | | | | | ratio | $E_o$ | 13 |
| 14 | $d_1$ | ft | | | | | | ft / ft | $S_e$ | 14 |
| 15 | $d_2$ | ft | | | | | | ft | $d_1$ | 15 |
| 16 | A | sq ft | | | | | | ft | $L_T$ | 16 |
| 17 | V | fps | | | | | | ratio | $L/L_T$ | 17 |
| 18 | $V_o$ | fps | | | | | | ratio | E | 18 |
| 19 | $R_f$ | ratio | | | | | | cfs | $Q_i$ | 19 |
| 20 | $R_s$ | ratio | | | | | | cfs | $Q_b$ | 20 |
| 21 | E | ratio | | | | | | | | |
| 22 | $Q_i$ | cfs | | | | | | | | |
| 23 | $Q_b$ | cfs | | | | | | | | |

## GRATE INLET CAPACITY PROCEDURES
### CONTINUOUS GRADE - COMPOSITE CROSS SLOPE

Using the **INLET DESIGN FORM** ( **FORM 4** ):

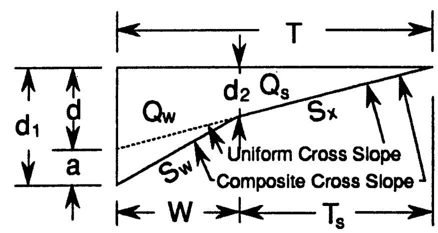
1. Note inlet Standard Plan No., dimensions, ( W, L & a ) and location or No.
2. Note Manning's coefficient of roughness, n ( normally 0.018 ).
3. Determine and note the street geometrics ( cross slope, $S_x$ ; longitudinal slope, S ) using the street design and / or survey ( see **STREET GEOMETRICS, CHARTS 25 & 26** )

Determine the following from known quantities, calculations or noted charts:

4. $S_w = S_x + (a / W)$
5. $S_w / S_x$
* 6. T ( Use maximum allowable width of flow or other known width. )
7. $T_s = T - W$
8. $Q_s n$ ( **CHART 30** )
9. $Q_s = Q_s n / n$
10. W / T
11. $E_o$ ( **CHART 31** )
12. $Q = Q_s/(1-E_o)$
13. $Q_w = Q - Q_s$
14. $d_1 = TS_x + a$ (for T > W)
    $d_1 = TS_w$ (for $T \leq W$)
15. $d_2 = (T-W) S_x$
16. $A = \left(\frac{d_1 + d_2}{2} W\right) + \left(\frac{d_2 T_s}{2}\right)$
17. $V = Q / A$
18. $V_o$ ( **CHART 27** )
19. $R_f = 1 - 0.09 (V_o - V)$ if $V > V_o$
    $R_f = 1$ if $V \leq V$
20. $R_s = 1 \Big/ \left(1 + \frac{0.15\ V^{1.8}}{S_x\ L^{2.3}}\right)$
21. $E = R_f E_o + R_s (1 - E_o)$
22. $Q_i = E Q$
23. $Q_b = Q - Q_i$

* To determine T from a known Q, use **CHART 32**

- a gutter depression, inches
- A cross-sectional area of flow, sq ft
- $d_1$ depth of flow at the curb
- $d_2$ depth of flow at outside edge of depressed gutter
- E efficiency of a grate ( interception efficiency of an inlet )
- $E_o$ ratio of frontal flow to total gutter flow
- L length of the grate, ft
- n Manning's coefficient of roughness
- Q total gutter flow, cfs
- $Q_b$ the portion of total gutter flow which is not intercepted by an inlet ( bypass or carryover flow ), cfs
- $Q_i$ the portion of total gutter flow which is intercepted by an inlet ( intercepted flow ), cfs
- $Q_s$ side flow rate
- $Q_w$ flow in width W, cfs
- $R_f$ ratio of frontal flow intercepted to total frontal flow ( frontal flow interception efficiency )
- $R_s$ ratio of side flow intercepted to total side flow ( side flow interception efficiency )
- S pavement longitudinal slope, ft / ft
- $S_w$ depressed gutter cross slope
- $S_x$ pavement cross slope, ft / ft
- T total spread of water in the gutter, ft
- $T_s$ spread of water outside depressed gutter
- V velocity of flow in the gutter, fps
- $V_o$ gutter velocity where splash-over first occurs over a grate, fps
- W width of depressed gutter or grate, ft



## CURB INLET CAPACITY PROCEDURES
### CONTINUOUS GRADE - COMPOSITE CROSS SLOPE

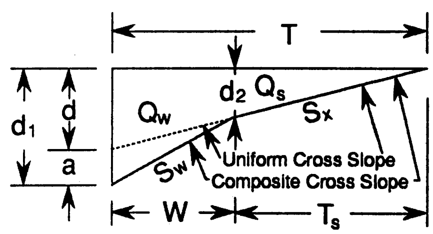
Using the **INLET DESIGN FORM** ( **FORM 4** ):

1. Note inlet Standard Plan No., dimensions, ( W, L & a ) and location or inlet No.
2. Note Manning's coefficient of roughness, n ( normally 0.018 ).
3. Determine and note the street geometrics ( cross slope, $S_x$ ; longitudinal slope, S ) using the street design and / or survey ( see **STREET GEOMETRICS, CHARTS 25 & 26** )

Determine the following from known quantities, calculations or noted charts:

4. $S'_w = a / W$ ( a in feet )
5. $S_w = S_x + S'_w$
6. $S_w/S_x$
7. K = 0.6 ( 0.076 if in S. I. )
* 8. T ( Use maximum allowable width of flow or other known width )
9. $T_s = T - W$
10. $Q_s n$ (**CHART 30**)
11. $Q_s = Q_s n / n$
12. W / T
13. $E_o$ ( **CHART 31** )
14. $S_e = S_x + S'_w E_o$
15. $d_1 = TS_x + a$ (for T>W)
$d_1 = TS_w$ (for T≤W)
16. $L_T = KQ^{0.42} S^{0.3} (1 / nS_e)^{0.6}$
17. $L / L_T$
18. $E = 1 - (1 - L / L_T)^{1.8}$
19. $Q_i = EQ$
20. $Q_b = Q - Q_i$

* To determine T from a known Q, use **CHART 32**




a gutter depression, inches
$d_1$ depth of flow at the curb
E efficiency of a grate ( interception efficiency of an inlet )
$E_o$ ratio of frontal flow to total gutter flow
K constant (0.6 or 0.076 if in S. I. )
L length of the grate, ft
n Manning's coefficient of roughness
Q total gutter flow, cfs
$Q_b$ the portion of total gutter flow which is not intercepted by an inlet ( bypass or carryover flow ), cfs
$Q_i$ the portion of total gutter flow which is intercepted by an inlet ( intercepted flow ), cfs
S pavement longitudinal slope, ft / ft
$S_w$ depressed gutter cross slope
$S_x$ pavement cross slope, ft / ft
T total spread of water in the gutter, ft
W width of depressed gutter or grate, ft

# Appendix J: Culverts

# Appendix J: Culverts

*(This Appendix is adapted from the BES 1991 "Sewer Design Manual", section 32, Culvert Hydraulic Design.)*

## 1. GENERAL INFORMATION

Culverts are conduits that convey stream flow through a roadway embankment or other type of obstruction such as driveways crossing roadside ditches. They may be constructed from a variety of materials and in many different shapes and configurations. Culverts are hydraulically complex. The design of culverts involves the determination of design flow, hydraulic performance, economy, pipe materials, horizontal and vertical locations and end designs. In some locations, the designer must provide for fish passage, wetland preservation or other environmental impacts. The design procedures, charts and forms in this appendix are limited to the type of culvert most commonly designed for a BES project; that is, a single barrel, round, concrete pipe of uniform size constructed with a straight slope and straight alignment. Do not use these culverts as a detention basin outlet, which require a more detailed analysis. If culverts are installed in fish bearing streams, the use of a bottomless culvert may be required.

## 2. DESIGN CALCULATIONS

The procedures, charts and forms for culvert design are taken from the Federal Highway Administration publication HYDRAULIC DESIGN OF HIGHWAY CULVERTS (Reference 10 in References at end of this appendix) The designer should become familiar with that publication and should refer to it for the design of any culvert that does not conform to the limitations of the information provided in this appendix. Design charts, forms and procedures for single barrel, round concrete pipe culverts are shown in CHART 33 through 37, FORM 5 and its accompanying PROCEDURE (see end of this appendix)

## 3. DESIGN PROCEDURES

Procedures have been developed (Ref. 10) for systematically analyzing culvert flow. Using those procedures, various types of flow are classified and analyzed based on a control section. A control section is a location where there is a unique relationship between the flow rate and the upstream water surface elevation. Many different flow conditions exist over time. At a given time the flow is either governed by (1) the inlet geometry (inlet control: the culvert barrel and outlet each have more capacity than the inlet); or (2) a combination of the culvert inlet configuration, the characteristics of the barrel, and the tailwater (outlet control: the culvert barrel or outlet has less capacity than the inlet). Control may oscillate from inlet to outlet; however, the described procedures are based upon the concept of "minimum performance." That is, while the culvert may operate more efficiently at times (more flow for a given headwater level), it will never operate at a lower level of performance than calculated (assuming good condition and no clogging.)

## 4. HEADWATER AND TAILWATER DEPTHS

The allowable headwater depth must be determined by an evaluation of the site. For economy, the headwater depth should be as great as practical as long as it does not compromise safety, flood plain regulations, environmental considerations or property rights. Designs should always include an evaluation of the impact of a 100-year flood and the results of roadway overtopping.

Conditions downstream of the culvert may cause the tailwater to rise above the outlet invert. The depth of tailwater is an important factor in determining the capacity of culverts flowing with outlet control and may change the minimum performance from inlet control to outlet control. Where there is a downstream obstruction or other cause for submergence of the outlet invert, the tailwater depth must be calculated. The tailwater depth may have a significant effect on the depth of the headwater.

## 5. DEBRIS CONTROL

Accumulation of sediment or debris in or near a culvert entrance will reduce the effective entrance cross-sectional area and will cause turbulence. Trash racks and safety grates placed over a culvert entrance will also cause turbulence. The turbulence is increased when debris is trapped. Turbulence at the culvert entrance reduces culvert capacity. Often the debris that is trapped could pass through the culvert without clogging. Grates directly over the entrance should be avoided wherever possible. Where debris too large to pass through the culvert is anticipated, debris control structures should be placed far enough upstream to allow subsidence of turbulence before the flow reaches the culvert entrance, but down stream of major debris sources. The design of debris control structures should comply with the Federal Highway Administration publication DEBRIS-CONTROL STRUCTURES (Reference No. 11)

Regardless of the best design efforts to control debris, it is always possible for culverts to become clogged. Therefore, all roadway fills should be evaluated for the results of headwater depths greater than design and of roadway overtopping.

## 6. TAPERED INLETS

Side tapered and slope tapered inlets (improved inlets) are flared culvert inlets with enlarged face sections and a hydraulically efficient throat section. They may include a depression (FALL) to further enhance their efficiency. Some may have mitered faces. Tapered inlets may be costly; however, their use may be economically justified in some cases. They should especially be considered as additions to existing inadequate culverts to avoid replacement, and on long culverts to reduce the barrel size. They should be designed using Reference No. 10.

## 7. Alignment and Grade

Wherever practical, culverts must be placed on a straight alignment and grade and should have straight entrance and exit channels. The alignment and grade should be as close as possible to the natural streambed. When conditions make the ideal alignment and grade impractical, the designer should consider relocation of a portion of the channel or small angle bends.

## 8. Culvert End Structures

Both the inlet and outlet ends of all culverts must be protected by an end structure of some type. The minimum requirement is a straight end wall. (Sewer Pipe Anchor Walls, Standard Plan 4-04, may be suitable for small culverts.) For adequate protection, it may be necessary to add riprap or to construct wingwalls or energy dissipaters.

## 9. Minimum and Maximum Velocities

Culverts should be designed with self-cleaning velocities at the entrance and in the barrel. The minimum velocity at design flow should be 3 feet per second to minimize silting and deposit of debris. The maximum velocity at design flow should be 10 feet per second to minimize abrasion of the culvert barrel and streambed scour and bank erosion at the outlet. Riprap or other type of revetment must be placed at the outlets of all culverts, unless it can be shown that expected outlet velocities will not cause streambed scour or bank erosion. Extreme velocities may require use of an energy dissipater. The design of riprap and energy dissipaters should comply with the Federal Highway Administration publications DESIGN OF RIPRAP REVETMENT (for large streams -more than 50 cfs) (Reference No. 12) or DESIGN OF ROADSIDE. CHANNELS WITH FLEXIBLE LININGS (for small streams -less than 50 cfs) (Reference No. l5), and HYDRAULIC DESIGN OF ENERGY DISSIPATORS FOR CULVERTS AND CHANNELS (Reference No. 14).

## 10. Other Design Criteria

Culverts are to be constructed of round pipe or as concrete box structures. (Also see Chapter 4 of Sewer and Drainage Facilities Design Manual (SDFDM).) The value of the roughness coefficient, n, in Manning's equation shall be 0.013. Other materials require approval before design. The value of n will be determined at the time of approval. The minimum size for culverts shall be 12" diameter.

All culvert entrances must be designed using the most efficient entrance coefficient which is practical. An entrance loss coefficient of 0.2 should be possible on most culverts by beveling of the entrance or other methods. (See CHART 35, ENTRANCE LOSS COEFFICIENTS.)

Stormwater flow designs for culverts are determined by the methods described in Chapters 6 and 8 of the SDFDM

**References** (in the above text and the following charts):

From: US Dept. of Transportation, Federal Highway Administration (FHWA), Washington, D.C.

10. HYDRAULIC DESIGN OF HIGHWAY CULVERTS (HDS 5) 1985,
 FHWA # IP-85-15, NTIS # PB86-196961 / AS.

11. DEBRIS-CONTROL STRUCTURES (HEC 9) 1971,
 FHWA # EPD-86-106, NTIS # PB86-179801 / AS.

12. DESIGN OF RIPRAP REVETMENT (HEC 11) 1989,
 FHWA # IP-89-016, NTIS # PB86-179793 / AS.

13. DRAINAGE OF HIGHWAY PAVEMENTS (HEC 12) 1984,
 FHWA # TS-84-202, NTIS # PB84-215003 / AS.

14. HYDRAULIC DESIGN OF ENERGY DISSIPATORS FOR CULVERTS AND CHANNELS (HEC 14) 1983,
 FHWA # EPD-86-1107, NTIS # PB86-180205 / AS.

15. DESIGN OF ROADSIDE CHANNELS WITH FLEXIBLE LININGS (HEC 15) 1988,
 FHWA # IP-87-7, NTIS # PB89-122584 / AS.

# MANNING'S EQUATION SOLUTION

## CAPACITY OF CIRCULAR PIPE RUNNING FULL

| d Dia. inches | D Dia. feet | A Area sq. ft. | R Hydr'l'c Radius feet | $R^{0.67}$ | $AR^{0.67}$ | MANNING'S VALUES ($M_v$) $M_v$ = Values of $\frac{1.486}{n} AR^{0.67}$ for various n: .010 | .013 | .015 |
|---|---|---|---|---|---|---|---|---|
| 6 | .50 | .20 | .125 | .250 | .049 | 7.28 | 5.61 | 4.86 |
| 8 | .67 | .35 | .167 | .303 | .106 | 15.75 | 12.08 | 10.47 |
| 10 | .83 | .55 | .208 | .351 | .191 | 28.38 | 21.91 | 18.99 |
| 12 | 1.00 | .78 | .250 | .397 | .312 | 46.36 | 35.63 | 30.88 |
| 15 | 1.25 | 1.23 | .312 | .461 | .566 | 84.11 | 64.60 | 55.98 |
| 18 | 1.50 | 1.77 | .375 | .520 | .919 | 136.6 | 105.0 | 91.04 |
| 21 | 1.75 | 2.41 | .437 | .576 | 1.385 | 205.8 | 158.4 | 137.3 |
| 24 | 2.00 | 3.14 | .500 | .630 | 1.979 | 294.1 | 226.2 | 196.1 |
| 27 | 2.25 | 3.98 | .562 | .681 | 2.708 | 402.4 | 309.6 | 268.3 |
| 30 | 2.50 | 4.91 | .625 | .731 | 3.588 | 533.2 | 410.2 | 355.5 |
| 36 | 3.00 | 7.07 | .750 | .825 | 5.832 | 866.6 | 667.0 | 578.1 |
| 42 | 3.50 | 9.62 | .875 | .915 | 8.803 | 1308 | 1006 | 871.9 |
| 48 | 4.00 | 12.6 | 1.00 | 1.00 | 12.57 | 1867 | 1436 | 1244 |
| 54 | 4.50 | 15.9 | 1.125 | 1.082 | 17.21 | 2557 | 1966 | 1704 |
| 60 | 5.00 | 19.6 | 1.25 | 1.16 | 22.78 | 3385 | 2604 | 2257 |
| 66 | 5.50 | 23.8 | 1.375 | 1.236 | 29.37 | 4364 | 3358 | 2910 |
| 72 | 6.00 | 28.3 | 1.50 | 1.310 | 37.04 | 5504 | 4235 | 3670 |
| 78 | 6.50 | 33.2 | 1.625 | 1.382 | 45.86 | 6815 | 5242 | 4543 |
| 84 | 7.00 | 38.5 | 1.75 | 1.452 | 55.88 | 8304 | 6388 | 5536 |
| 90 | 7.50 | 44.2 | 1.875 | 1.521 | 67.20 | 9985 | 7678 | 6654 |
| 96 | 8.00 | 50.3 | 2.00 | 1.587 | 79.77 | 11854 | 9120 | 7904 |
| 102 | 8.50 | 56.7 | 2.125 | 1.653 | 93.80 | 13939 | 10721 | 9291 |
| 108 | 9.00 | 63.6 | 2.25 | 1.717 | 109.2 | 16232 | 12486 | 10821 |
| 114 | 9.50 | 70.9 | 2.375 | 1.780 | 126.2 | 18749 | 14422 | 12499 |
| 120 | 10.00 | 78.5 | 2.50 | 1.842 | 144.7 | 21498 | 16537 | 14332 |
| 126 | 10.50 | 86.6 | 2.625 | 1.902 | 164.7 | 24486 | 18834 | 16323 |
| 132 | 11.00 | 95.0 | 2.75 | 1.963 | 186.5 | 27721 | 21322 | 18479 |
| 138 | 11.50 | 103.9 | 2.875 | 2.022 | 210.1 | 31209 | 24005 | 20805 |
| 144 | 12.00 | 113.1 | 3.00 | 2.080 | 235.2 | 34957 | 26891 | 23305 |
| 150 | 12.50 | 122.7 | 3.125 | 2.137 | 262.2 | 38970 | 29983 | 25985 |
| 156 | 13.00 | 132.7 | 3.25 | 2.194 | 291.1 | 43274 | 33289 | 28850 |
| 162 | 13.50 | 143.1 | 3.375 | 2.250 | 322.0 | 47859 | 36814 | 31905 |
| 168 | 14.00 | 153.9 | 3.50 | 2.305 | 354.7 | 52727 | 40563 | 35154 |
| 174 | 14.50 | 165.1 | 3.625 | 2.360 | 389.6 | 57910 | 44542 | 38603 |
| 180 | 15.00 | 176.7 | 3.75 | 2.414 | 426.6 | 63391 | 48756 | 42255 |

**NOTE:** To obtain capacity (Q), multiply the values in the table ($M_v$) by the 0.5 power of the slope ($S^{0.5}$). $Q = M_v S^{0.5}$

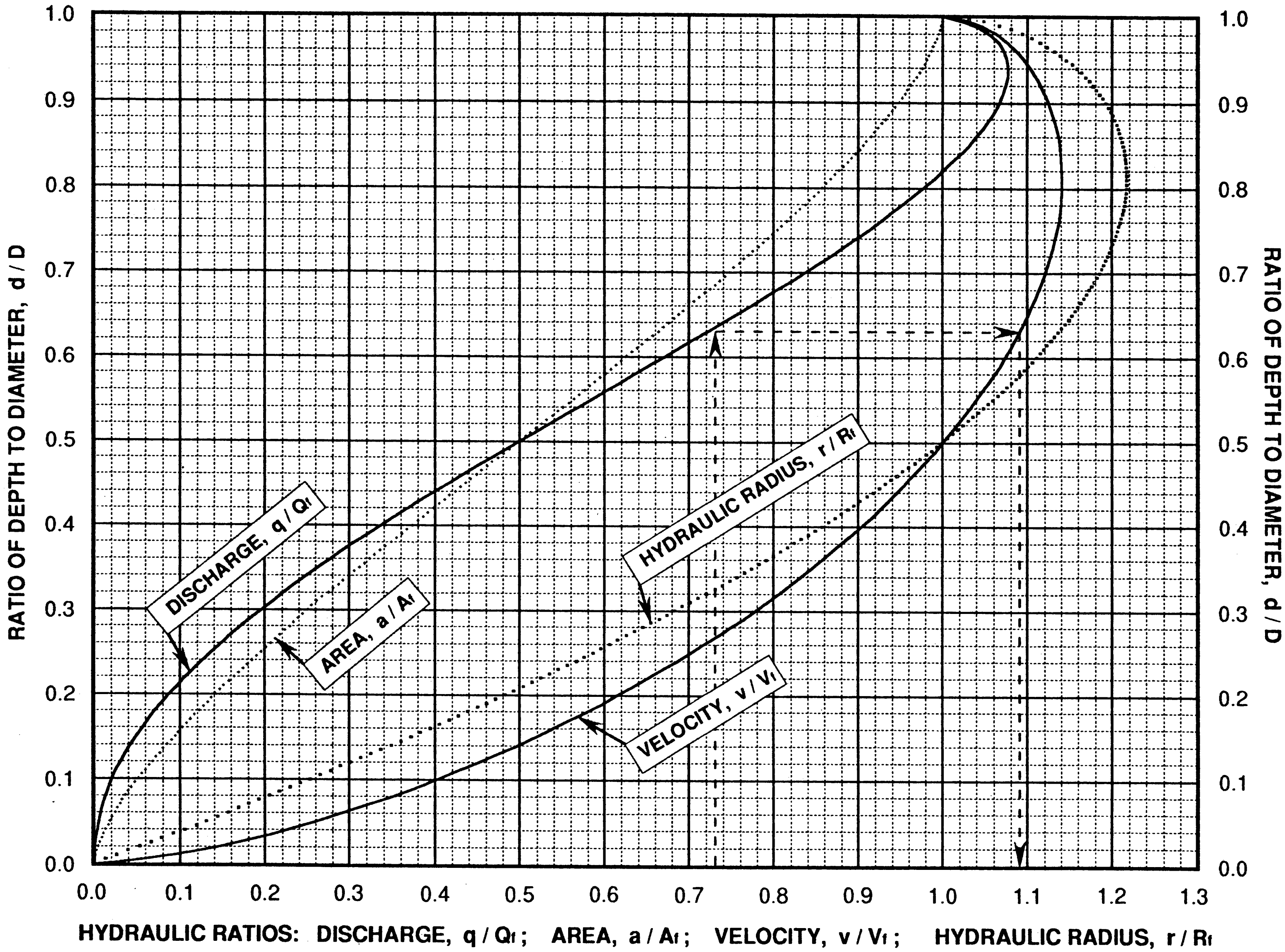
To obtain velocity (V), divide flow (Q) by the cross-sectional area of the pipe (A). $V = Q/A$

To find the Manning's value ($M_v$) for any n, divide 0.010 by the desired n, then multiply the result times the value ($M_v$) for n = 0.010. $M_{v\,(\text{for desired n})} = \frac{.010}{n} M_{v\,(\text{for n = .010})}$

To obtain partial flow factors for circular pipe, refer to **CHART 5, HYDRAULIC RATIOS OF A CIRCULAR SECTION.**

**EXAMPLE:** 30" pipe @ n = .013 & slope = 1.00% (.01 ft/ft); $M_v = 410.2$, $S^{0.5} = .01^{0.5} = .1$, $Q = 410.2 \times .1 = 41.02$ cfs, $A = 4.91$ sq. ft., $V = 41.02 / 4.91 = 8.4$ fps

## HYDRAULIC RATIOS OF A CIRCULAR SECTION




EXAMPLE:

Given; 30" (2.5') dia. pipe @ 0.01 ft/ft slope & n = 0.013, $Q_f$ = 41.0 cfs, $V_f$ = 8.4 fps. (see **CHART 4, MANNING'S EQUATION SOLUTION**)

Find; Depth and velocity when q = 30.0 cfs.

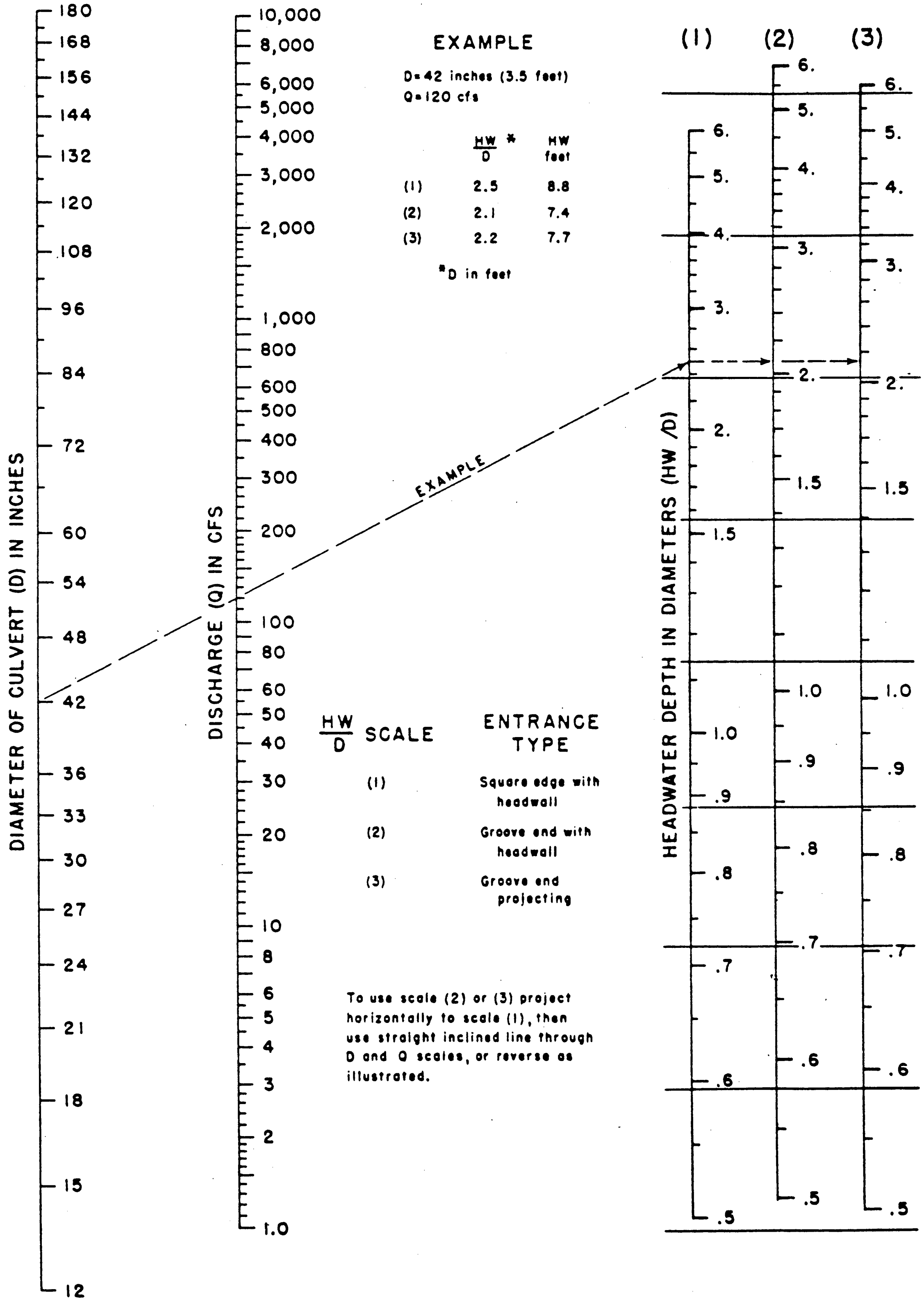
Solution; $q / Q_f$ = 30.0 / 41.0 = 0.73

Enter chart on x axis at 0.73, project up to the discharge line & read depth to diameter ratio = 0.63

Project right to the velocity line & read velocity to velocity full ratio = 1.09

When q = 30.0 cfs, depth = 2.5' x 0.63 = 1.58' & velocity = 8.4 x 1.09 = 9.2 fps.

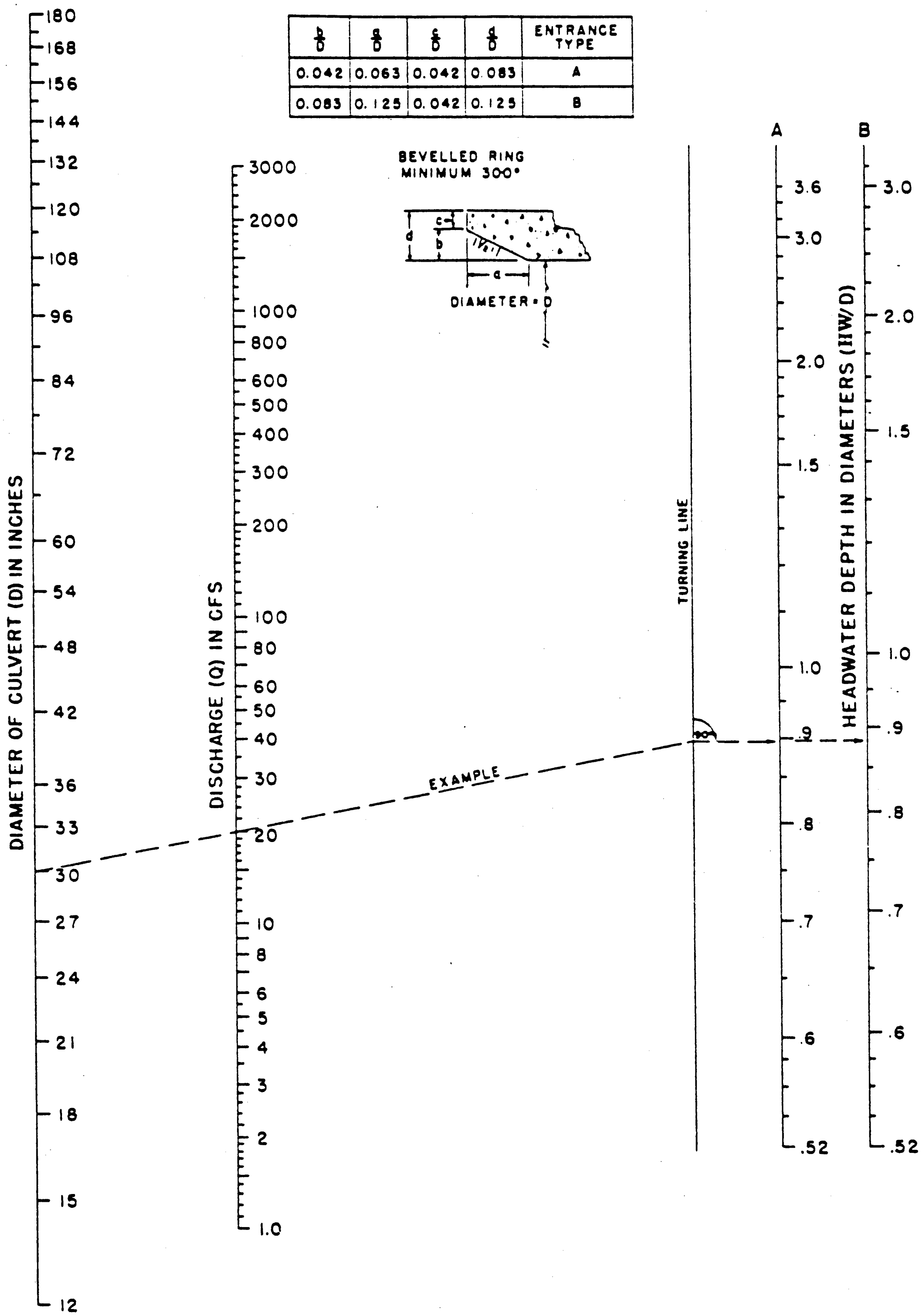
# HEADWATER DEPTH
## FOR CIRCULAR CONCRETE PIPE CULVERTS
## INLET CONTROL




From Ref. No. 10, Chart 1, Page 181.

# HEADWATER DEPTH
## FOR CIRCULAR PIPE CULVERT WITH BEVELED RING ENTRANCE
## INLET CONTROL

| b/D | a/D | c/D | d/D | ENTRANCE TYPE |
|---|---|---|---|---|
| 0.042 | 0.063 | 0.042 | 0.083 | A |
| 0.083 | 0.125 | 0.042 | 0.125 | B |




From Ref. No. 10, Chart 3, Page 183.

# ENTRANCE LOSS COEFFICIENTS

Outlet Control, Full or Partly Full Entrance Head Loss

$$H_e = k_e ( V^2 / 2g )$$

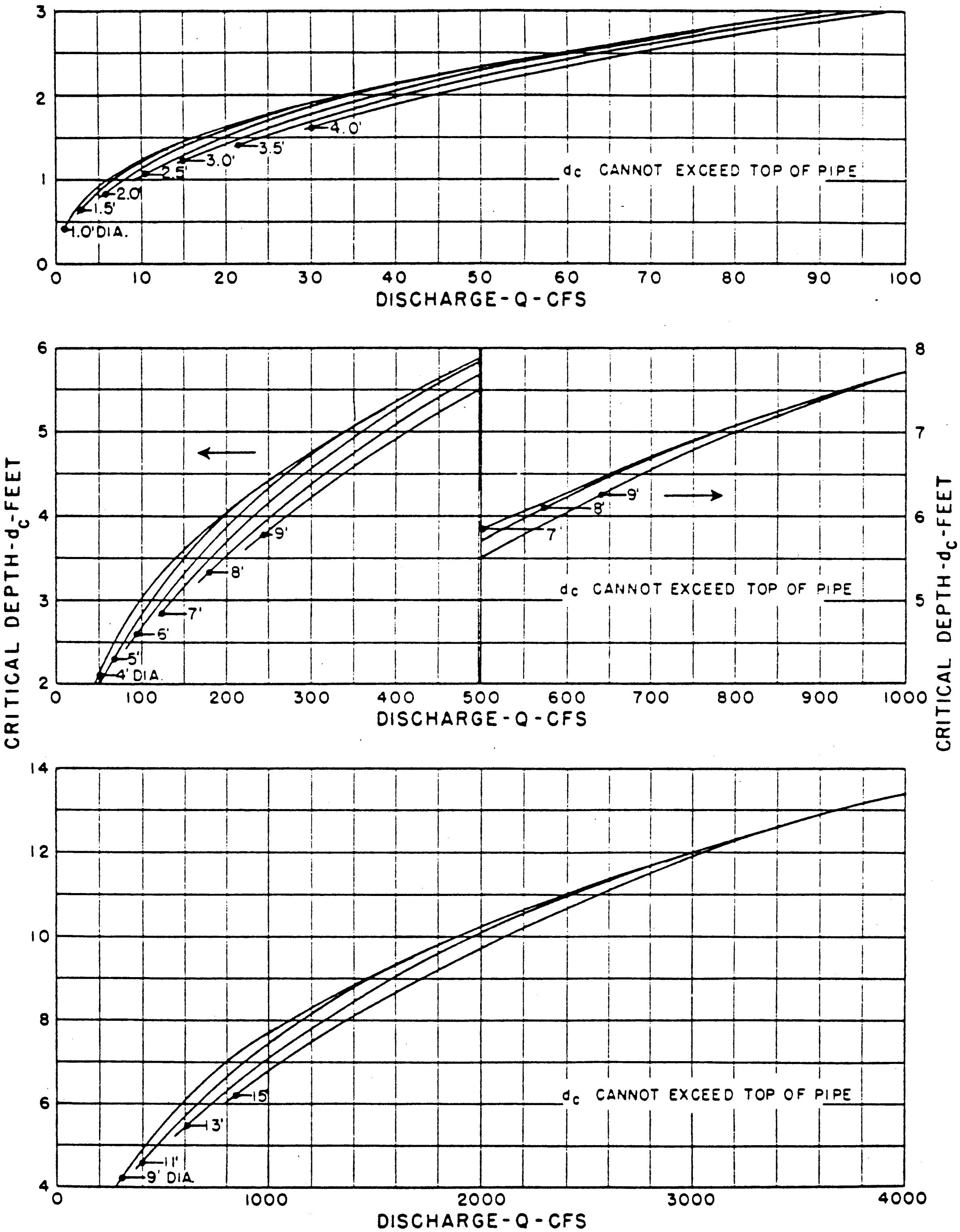
| Type of Structure and Design of Entrance | Coefficient $k_e$ |
|---|---|
| **Pipe, Concrete** | |
| Projecting from fill, socket end (groove end) | 0.2 |
| Projecting from fill, square cut end | 0.5 |
| Headwall or headwall and wingwalls | |
| Socket end of pipe | 0.2 |
| Square-edge | 0.5 |
| Rounded (radius = 1/12D) | 0.2 |
| Mitered to conform to fill slope | 0.7 |
| *End-Section conforming to fill slope | 0.5 |
| Beveled edges, 33.7° or 45° bevels | 0.2 |
| Side-tapered or slope-tapered inlet | 0.2 |
| **Pipe or Pipe-Arch, Corrugated Metal** | |
| Projecting from fill (no headwall) | 0.9 |
| Headwall or headwall and wingwalls, square-edge | 0.5 |
| Mitered to conform to fill slope, paved or unpaved slope | 0.7 |
| *End-Section conforming to fill slope | 0.5 |
| Beveled edges, 33.7° or 45° bevels | 0.2 |
| Side-tapered or slope-tapered inlet | 0.2 |
| **Box, Reinforced Concrete** | |
| Headwall parallel to embankment (no wingwalls) | |
| Square-edged on 3 edges | 0.5 |
| Rounded on 3 edges to radius of 1/12 barrel dimension, or beveled edges on 3 sides | 0.2 |
| Wingwalls at 30° to 75° to barrel | |
| Square-edged at crown | 0.4 |
| Crown edge rounded to radius of 1/12 barrel dimension, or beveled top edge | 0.2 |
| Wingwall at 10° to 25° to barrel | |
| Square-edged at crown | 0.5 |
| Wingwalls parallel (extention of sides) | |
| Square-edged at crown | 0.7 |
| Side-tapered or slope-tapered inlet | 0.2 |

*Note: "End-Section conforming to fill slope," made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests, they are equivalent in operation to a headwall in both inlet and outlet control. Some end sections, incorporating a closed taper in their design have a superior hydraulic performance.

From Ref. No. 10, Table 12, Page 179

BES August 7, 1990

# CRITICAL DEPTH
## CIRCULAR PIPE

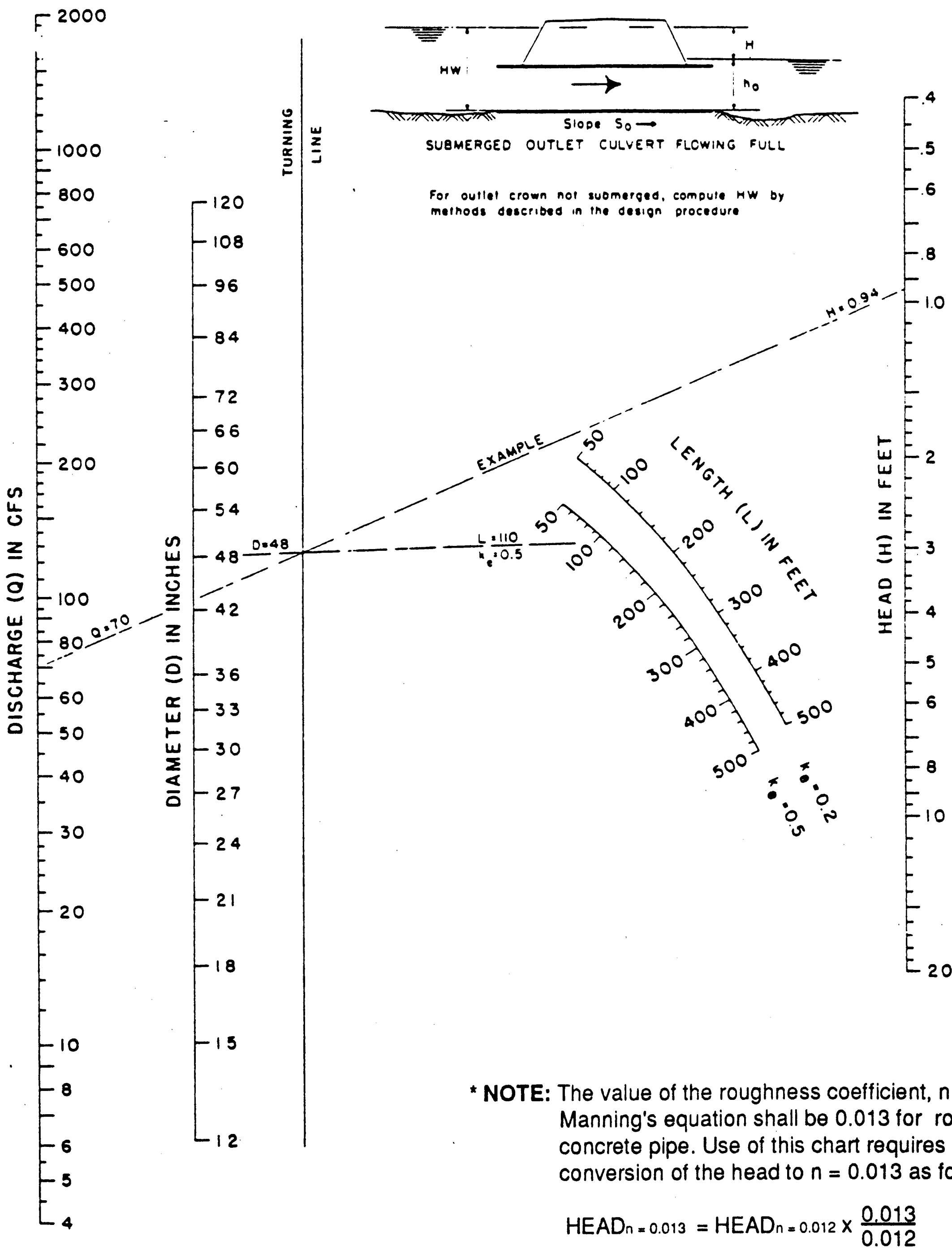



From Ref. No. 10, Chart 4, Page 184.

BES August 7, 1990

# HEAD
## FOR ROUND CONCRETE PIPE CULVERTS FLOWING FULL
## OUTLET CONTROL

n = 0.012*




*** NOTE:** The value of the roughness coefficient, n, in Manning's equation shall be 0.013 for round concrete pipe. Use of this chart requires conversion of the head to n = 0.013 as follows:

$$HEAD_{n=0.013} = HEAD_{n=0.012} \times \frac{0.013}{0.012}$$

$$= HEAD_{n=0.012} \times 1.083$$

From Ref. No. 10, Chart 5, Page 185.

# CULVERT DESIGN FORM

| PROJECT: ______________________ | STATION: ______________ SHEET ____ OF ____ | CULVERT DESIGN FORM<br>DESIGNER / DATE: ______ / ______<br>REVIEWER / DATE: ______ / ______ |
|---|---|---|

## HYDROLOGICAL DATA

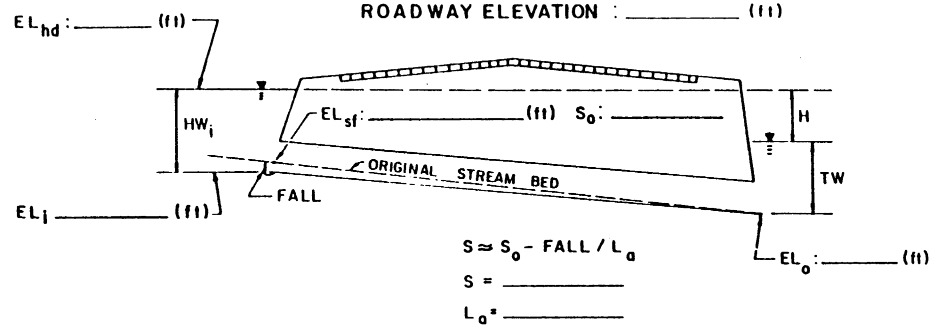
(SEE ADD'L. SHTS.)

- ☐ METHOD: ______
- ☐ DRAINAGE AREA: ______ ☐ STREAM SLOPE: ______
- ☐ CHANNEL SHAPE: ______
- ☐ ROUTING: ______ ☐ OTHER: ______

## DESIGN FLOWS/TAILWATER

| R.I. (YEARS) | FLOW (cfs) | TW (ft) |
|---|---|---|
| | | |
| | | |

ROADWAY ELEVATION: ______ (ft)




$S \approx S_o - FALL / L_a$

S = ______

$L_a$ = ______

| CULVERT DESCRIPTION: MATERIAL - SHAPE - SIZE - ENTRANCE | TOTAL FLOW Q (cfs) | FLOW PER BARREL Q/N (1) | HEADWATER CALCULATIONS: INLET CONTROL $HW_i/D$ (2) | $HW_i$ | FALL (3) | $EL_{hi}$ (4) | OUTLET CONTROL TW (5) | $d_c$ | $\frac{d_c+D}{2}$ | $h_o$ (6) | $k_e$ | H (7) | $EL_{ho}$ (8) | CONTROL HEADWATER ELEVATION | OUTLET VELOCITY | COMMENTS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |

## TECHNICAL FOOTNOTES:

(1) USE Q/NB FOR BOX CULVERTS

(2) $HW_i/D = HW/D$ OR $HW_i/D$ FROM DESIGN CHARTS

(3) $FALL = HW_i - (EL_{hd} - EL_{sf})$; FALL IS ZERO FOR CULVERTS ON GRADE

(4) $EL_{hi} = HW_i + EL_i$ (INVERT OF INLET CONTROL SECTION)

(5) TW BASED ON DOWN STREAM CONTROL OR FLOW DEPTH IN CHANNEL.

(6) $h_o = TW$ or $(d_c + D/2)$ (WHICHEVER IS GREATER)

(7) $H = \left[1 + k_e + (29 n^2 L) / R^{1.33}\right] V^2/2g$

(8) $EL_{ho} = EL_o + H + h_o$

## SUBSCRIPT DEFINITIONS:

- a. APPROXIMATE
- f. CULVERT FACE
- hd. DESIGN HEADWATER
- hi. HEADWATER IN INLET CONTROL
- ho HEADWATER IN OUTLET CONTROL
- i. INLET CONTROL SECTION
- o. OUTLET
- sf. STREAMBED AT CULVERT FACE
- tw. TAILWATER

## COMMENTS / DISCUSSION:

## CULVERT BARREL SELECTED:

SIZE: ______

SHAPE: ______

MATERIAL: ______ n: ______

ENTRANCE: ______

From Ref. No. 10, Page 240

BES August 7, 1990

## CULVERT DESIGN PROCEDURES

Single Barrel, Circular, Concrete Pipe *

1. Determine the stormwater design flow and the flow for a 100 year storm (see page **26-1 & 26-2, QUANTITY OF STORMWATER**).

2. Using the **CULVERT DESIGN FORM** ( **FORM 5** ):

   a. Identify the project, project no., location, designer, date, etc.

   b. Summarize all known data for the culvert ( hydrological, flows, depths, elevations, etc. )

   c. Select an entrance type, then choose a trial culvert size using **CHART 33, HEADWATER DEPTH, INLET CONTROL** or **CHART 34** if using 1.5 : 1 beveled ring entrance. <u>Use of a beveled ring entrance is recommended</u>. Use an estimated headwater over culvert height, HW / D, for this step.

   d. INLET CONTROL CALCULATIONS: using the trial culvert size, from the inlet control nomograph;
   { enter the trial culvert material, shape, size & entrance type.
   { find the accurate HW / D
   { calculate the headwater, HWi, [ multiply (HW / D) x D ]
   { add the result to the invert elevation, ELi, ( subtract FALL if used )
   The total is the headwater elevation required for the culvert to pass the flow in inlet control, ELhi.

   e. OUTLET CONTROL CALCULATIONS; using the trial culvert size;
   { determine the tailwater depth, TW, above the outlet invert
   { find the critical depth, $d_c$, using **CHART 36, CRITICAL DEPTH** ( $d_c$ cannot exceed D)
   { calculate $(d_c + D) / 2$
   { determine the depth from the outlet invert to the hydraulic grade line, [ $h_o$ = the larger of TW or $(d_c + D)/2$.
   { find the appropriate entrance loss coefficient, $k_e$, from **CHART 35, ENTRANCE LOSS COEFFICIENTS** .
   { determine the culvert barrel losses, H, using **CHART 37, HEAD FOR OUTLET CONTROL** .
   { calculate $EL_o + h_o + H = EL_{ho}$.
   The total is the headwater elevation required to pass the flow in outlet control, $EL_{ho}$.

   f. Determine the controlling headwater elevation. The controlling headwater elevation is the higher of $EL_{hi}$ ( inlet control governs ) or $EL_{ho}$ ( outlet control governs ).

   g. Determine the outlet velocity. ( Using **CHART 4, MANNING'S EQUATION SOLUTION** and **CHART 5, HYDRAULIC RATIOS OF A CIRCULAR SECTION** ).If inlet control governs determine the normal depth and velocity in the culvert barrel. The velocity at normal depth is assumed to be the outlet velocity. If outlet control governs, determine the area of flow at the outlet based on the barrel geometry and the following; ( 1 ) critical depth if the tailwater is below critical depth; ( 2 ) the tailwater depth if the tailwater is between critical depth and the top of the barrel; ( 3 ) the height of the barrel if the tailwater is above the top of the barrel.

   h. If the controlling elevation is not acceptable, if costs could be reduced using a smaller culvert or if there are other unacceptable factors ( excessive outlet velocity, etc. ), repeat steps 2d through 2g until an acceptable culvert is found.

   i. Repeat steps 2d through 2g using the flow for a 100 year storm. Continue repeating steps 2d and 2e until a culvert is found that is acceptable for all conditions.

   j. Complete the Comments / Discussion and Culvert Barrel Selected sections of the form.

   k. If the selected culvert will not fit the site, return to the culvert design process and select another culvert.

3. If, for any reason, the performance of the culvert is critical, develop a performance curve using the methods described in **Ref. No. 10.**

* Use similar procedures for other materials and shapes. Charts & forms are available in **Ref. No. 10**.
* Refer to **Ref. No. 10** for the design of culverts not conforming to the limitations of these procedures.

# Appendix K: Chapter 5 Designing and Avoiding Odor and Corrosion in New Wastewater Collections Systems, US Environmental Protection Agency

## Chapter 5

## Designing to Avoid Odor and Corrosion in New Wastewater Collection Systems

### 5.1 Introduction

The potential for sulfide and odor generation in new sewer systems must be fully evaluated in the design stage based on the characteristics and properties of odor-causing compounds and the principles of control described in Chapters 2 and 3 of this manual.

Warm temperatures, flat topography and large sewer service areas are physical conditions which, unless specifically considered during design, are likely to result in sulfide odors and sulfide-induced corrosion within the collection systems. Proper selection of slopes, rational design of hydraulic structures such as drops and junctions, proper design of pumping stations, wet wells, holding basins, and force mains along with the provision of adequate ventilation are all critical elements of a total sewer system design that are necessary to minimize sulfide generation potential.

Although designing to avoid sulfide generation may increase the capital cost of a new sewer system, this approach is technically and economically preferable to having to control sulfides after they become a problem.

This chapter provides guidance for eliminating or minimizing the generation of sulfides in the design of new wastewater collection systems. Specific reference is made to control of $H_2S$, since this is the most prevalent odor source associated with wastewater conveyance systems.

Design procedures outlined for sulfide control will often be applicable for control of other odor-producing compounds present in municipal wastewater, since many of the design concepts presented deal with preventing the anaerobic conditions under which undesirable odors are more likely to occur.

### 5.2 Hydraulic Design

#### *5.2.1 Slope*

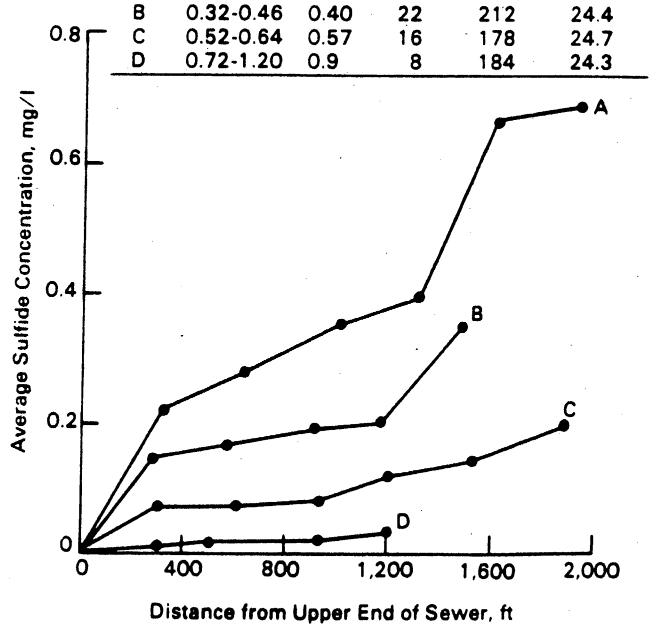
Slope is the key criterion in designing a wastewater collection system to avoid sulfide problems. Sewers designed with long runs at minimum slope are prone to sulfide generation due to long residence times, poor oxygen transfer, and deposition of solids. Sulfide generation can be a serious problem in new sewers, where actual flows are much less than design flows during the early lifetime of the system, and velocities are inadequate to maintain solids in suspension.

In the 1950's, a study was made of small collecting sewers in southern California. The sewers, all 15 and 20 cm (6 and 8 in) in diameter, were divided into four slope classes. The results from this study are shown in Figure 5-1 (1). This figure clearly shows the effect of slope and sewer length on sulfide generation. Steeper slopes increase turbulence and oxygen transfer, thus maintaining aerobic conditions in the wastewater and preventing significant sulfide generation. Although the values shown in Figure 5-1 for average sulfide concentration appear relatively low, peak sulfide concentrations were as much as four times the average (1).

In designing a wastewater collection system to minimize sulfide generation, velocities should be

**Figure 5-1. Sulfide occurrence in small sewers (1).**

| Line | Slope (%) Range | Slope (%) Avg. | No. of Sewers | Avg. Results BOD | Avg. Results Temp. (°C) |
|---|---|---|---|---|---|
| A | 0.20-0.25 | 0.23 | 18 | 253 | 24.7 |
| B | 0.32-0.46 | 0.40 | 22 | 212 | 24.4 |
| C | 0.52-0.64 | 0.57 | 16 | 178 | 24.7 |
| D | 0.72-1.20 | 0.9 | 8 | 184 | 24.3 |



sufficient to prevent deposition of solids. Current conventional design practice recommends that a minimum velocity of 0.6 m/s (2 ft/s) be achieved regardless of pipe size to maintain a self-cleaning action in sewers. Another approach is to maintain a minimum boundary shear stress to prevent suspended particles from settling out on the invert.

The minimum horizontal velocity required to suspend particles of known characteristics can be computed using the following equation (2):

$$V_H = \frac{8k(s-1)gd^{1/2}}{f} \qquad (5\text{-}1)$$

where,

$V_H$ = horizontal velocity that will just produce scour, m/s

k = constant which depends on type of material being scoured (typically 0.04 to 0.06)

s = specific gravity of particles

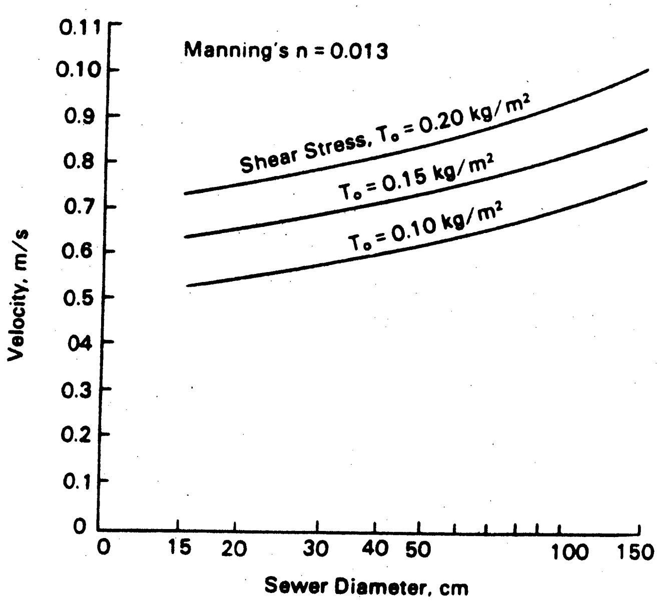
g = acceleration due to gravity = 9.8 $m/s^2$

d = diameter of particles, m

f = Darcy-Weisbach friction factor (typically 0.02 to 0.03)

If required minimum velocity is established based on maintaining a constant boundary shear stress, minimum velocities deviate from the recommended 0.6 m/s (2 ft/s) as a function of pipe size. Figure 5-2 shows minimum velocities required to maintain a constant shear stress as a function of pipe size (3). If a boundary shear stress of $T_o$ = 0.15 $kg/m^2$ (0.03 $lb/ft^2$)

**Figure 5-2. Minimum scour velocity based on boundary shear stress (3).**




is used, the minimum velocity requirement exce 0.6 m/s (2 ft/s) at pipe diameters greater than 35 (14 in), but is less than 0.6 m/s (2 ft/s) at smaller p diameters. This suggests that larger pipes requ greater slopes to maintain adequate scouring velo ties. For sewers with Manning's n = 0.013 or less design boundary shear stress in the range of 0.15 0.20 $kg/m^2$ (0.03-0.04 $lb/ft^2$) will likely keep se cleaning sewer systems free from sulfide probler For sewers with n = 0.015 or greater, a design she stress of 0.2 $kg/m^2$ (0.04 $lb/ft^2$) should be used (3

It should be noted that the often recommended ( m/s (2 ft/s) is a minimum velocity. It is desirable have a velocity of 0.9 m/s (3 ft/s) or more whenev practical (2).

Pomeroy has developed guidance regarding flo slope relationships for preventing sulfide buildu This is shown as Figure 5-3 (1). The curves are bas on an assumed effective BOD (EBOD) of 500 mg. Here, EBOD represents the BOD during the da maximum 6-hour flow period during the three hotte months of the year. The calculation of EBOD f Figure 5-3 is:

$$EBOD = 1.25\ BOD_5 \times 1.07^{(T-20)} \qquad (5\text{-}$$

where,

EBOD = effective BOD, mg/l

1.25 = factor to convert average daily BOD maximum 6-hour flow BOD

$BOD_5$ = standard 5-day BOD, mg/l

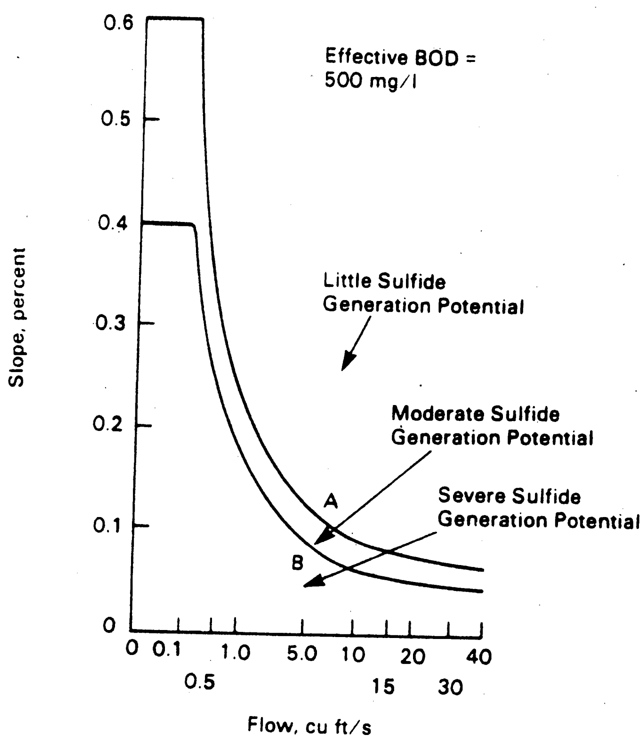
T = average wastewater temperature for thre hottest months, °C

In the development of Figure 5-3, it is assumed th the depth of flow does not exceed two-thirds of th pipe diameter, and that the effective slope is calcu lated upstream of the point of interest over distance representing flow times of approximately 1 hour.

With an assumed EBOD of 500 mg/l, a syste designed with a flow-slope relationship falling on above Curve A may be expected to produce very litt sulfide, rarely more than 0.1 to 0.2 mg/l of dissolve sulfide. Use of the flow-slope design points betwee Curves A and B may result in moderate sulfid concentrations which may cause odor and corrosio problems at points of high turbulence. Flow-slop design points falling below Curve B may result i substantial sulfide generation.

Figure 5-3 is intended only as a guide to predict whe sulfide generation is likely to be a problem for certai slopes and flows, and is not to be used for detaile design purposes. Where wastewater characteristic vary from the assumed EBOD of 500 mg/l, the flow

Figure 5-3. Flow—slope relationships as guides to sulfide forecasting (1).




slope relationships will increase or decrease in proportion to the square roots of the ratio of EBOD's. For a design EBOD other than 500 mg/l the minimum acceptable slope can be calculated according to (4):

$$S_D = \frac{EBOD_D^{1/2}}{500} \times S_c \qquad (5\text{-}3)$$

where,

$S_D$ = minimum acceptable slope for design EBOD

$S_c$ = minimum slope from Figure 5-3

$EBOD_D$ = design EBOD (mg/l)

Figure 5-3 is based on the average slope of sewer runs with lengths ranging from 365 to 580 m (1,200 to 1,900 ft). Even if the necessary average slope to prevent sulfide generation is attained, specific reaches should be checked to ensure that self-cleaning velocities are maintained where feasible, and that a minimum scouring velocity of 0.6 m/s (2 ft/s) is maintained during peak daily flow conditions. The recommended scouring velocity of 0.6 m/s (2 ft/s) for pipes flowing one-half full at design flow can result in velocities as low as 0.2 m/s (0.67 ft/s) during low flow periods early in the design lifetime of the system, thus allowing deposition of sewage solids. While this is undesirable, it cannot be economically avoided in certain instances. Sulfide generated from accumulated solids is generally much less critical than that generated from the slime layer, especially when the accumulated solids are flushed from the system on a daily basis.

Choice of a design slope depends on several factors other than flow and EBOD, including topography, subsurface conditions, depth of service laterals, pipe size and material, as well as overall economic trade-offs between gravity flow vs. pumped systems. If sewage pumping is required, a savings in pumping head by minimizing slopes should not, by itself, be a reason for using slopes that will result in significant sulfide generation. If choice of slopes for use in Figure 5-3 results in points falling on or below Curve B, indicating high potential for sulfide generation, Equation 2-25 should be used to calculate estimated sulfide buildup. Equation 2-28 can then be used to estimate the rate of corrosion of the pipe material. If the corrosion rate is such that the expected lifetime of the pipe is less than the design lifetime, several options are available to the engineer. These include use of steeper slopes or other means to promote natural reaeration, injection of air or oxygen, addition of chemicals, or selection of materials that are more resistant to corrosion. In general, the last option would be least desirable since, although rates of corrosion of pipe materials may be reduced, sulfide levels may still be high and may result in substantial odor generation.

Design lifetime is an important parameter in considering sulfide generation and subsequent corrosion of pipe materials in wastewater collection systems. EPA cost-effectiveness guidelines recommend a useful life of 50 years for wastewater conveyance structures, including collection systems, outfall pipes, interceptors, force mains, and tunnels. For special situations, as with sewers designed for interim service, shorter design lifetimes may be selected that are consistent with the planning objectives of the municipality.

### *5.2.2 Pipe Size*

If sulfide generation has been determined to be a potential problem, larger pipe sizes may be selected to improve the rate of reaeration. A larger pipe for the same flow rate and slope reduces the mean hydraulic depth (cross-sectional area of the stream divided by surface area), which increases surface area available for reaeration (Equation 2-14). Figure 2-9 shows that reducing the relative depth of flow from 0.75 to 0.5 approximately doubles the reaeration rate. Adequate scouring velocities must be maintained if larger pipe is used, but this is not normally a problem since for a given flow and slope, velocity is influenced very little by pipe size.

Force mains have often been constructed of minimum diameter pipe in order to reduce detention time and avoid sulfide buildup. However, the smaller pipe has a greater ratio of slime-supporting pipe wall to volume of wastewater, partially offsetting the benefit of reduced detention time. Choice of minimum pipe size is, therefore, not considered to be of significant value in reducing sulfide generation.

### *5.2.3 Drops and Falls*

For wastewater containing little or no dissolved sulfide, drop structures can result in the wastewater stream picking up substantial amounts of oxygen, helping to maintain aerobic conditions and preventing sulfide generation. However, for wastewater containing dissolved sulfide, the turbulence associated with drops or falls will release $H_2S$ from the stream, resulting in odors and corrosion.

The benefits of reaeration through drops and falls were discussed in Chapter 2. Figure 5-4 shows two alternatives for grading a sewer. Alternative A employs a lesser slope but allows free fall of the wastewater at manhole 2. Alternative B shows the more conventional approach of increasing the slope of the line between manholes 1 and 2. Table 5-1 was developed by Thistlethwayte to show the impact of the two alternative designs on oxygen absorption (5). Note that the expected oxygen absorption in the sewer using a drop of about 1.2 m (4 ft) is 50 times the oxygen absorption without the drop. If some DO were present in the influent to manhole 1, the ratio would remain the same, but the amounts of oxygen absorbed would be reduced in proportion to the actual oxygen saturation deficits. Whether or not such a drop could be justified would depend on the DO levels upstream and the desired DO level downstream. Considering a DO increase of more than 3 mg/l by the use of a drop, it may be possible to lay the downstream sections at a flatter grade without exhausting the DO added by the drop (5).

Typical drop manhole designs are shown in Figure 5-5 (6). Drops may be subject to clogging or stoppages due to bridging of sticks or other debris over the drc pipe. An alternate to the standard design places tr drop inside the manhole, allowing easy access to tr drop pipe. To avoid stoppages, the drop pipe may be ( a larger diameter.

**Table 5-1. Oxygen Absorption in a Sewer With and With a Drop (5)**

| | Alternative A* | Alternative B* |
|---|---|---|
| Dry weather flow, m³/min (max. 6 hr) | 3.4 | 3.4 |
| Sewer diameter, cm | 61 | 61 |
| Slope, percent | 0.1 | 0.5 |
| Wastewater velocity, m/s | 0.53 | 0.96 |
| Oxygen absorbed, mg/l (assuming saturation deficit of 10 mg/l) | | |
| In the sewer | 0.038 | 0.069 |
| At the drop | 3.18 | - |
| Total oxygen absorbed | 3.22 | 0.07 |

*Refer to Figure 5-4.

**Figure 5-5. Drop manhole designs (6).**

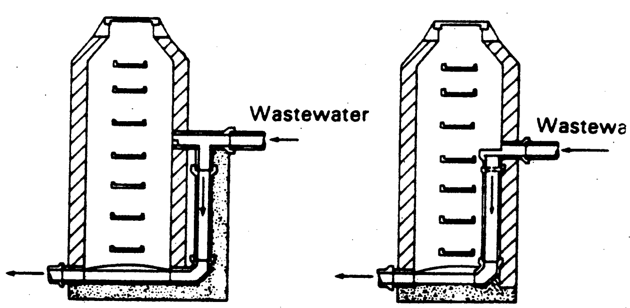
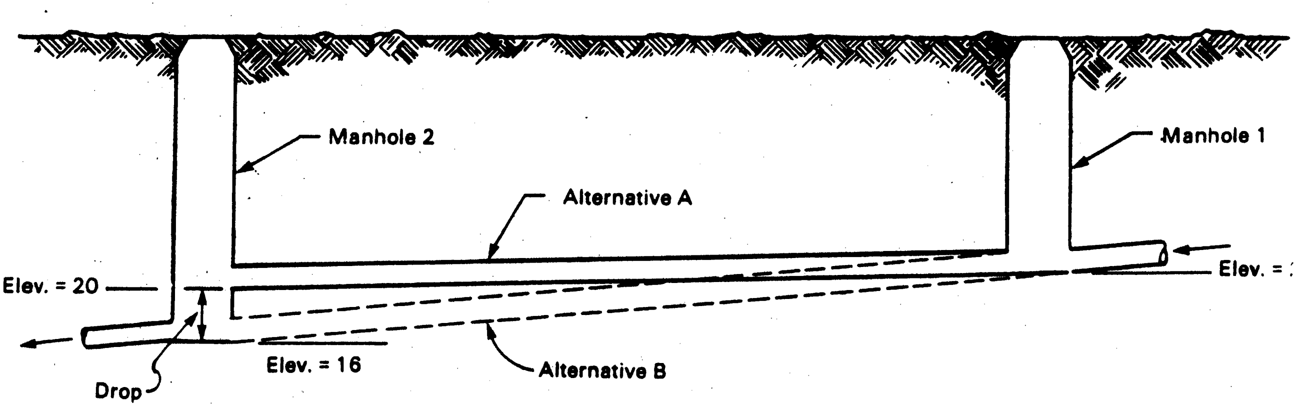



**Figure 5-4. Alternative sewer grading designs (5).**



For large flows and relatively large drop distances, vortex drops are sometimes used. In a vortex drop, the flow is directed tangentially to produce a spiral flow pattern. Advantages of vortex drops include: 1) maintenance of a continuous air core down the shaft; 2) excellent conditions for oxygen uptake; 3) no accumulation of solids or scum; 4) less likelihood of stoppages; and 5) better energy dissipation (5).

A diagram of a hydraulic fall is presented in Figure 3-17. Such designs are unlikely to have stoppages associated with sticks and debris, yet will provide substantial reaeration of the wastewater.

Drop manholes generally have not been used where it is economically feasible to steepen the sewer because of potential maintenance problems and increased construction costs (6). However, where sulfide generation potential exists, well designed drops and falls are effective techniques for maintaining aerobic conditions and preventing sulfide generation.

Drops or falls are generally not recommended when appreciable amounts of dissolved sulfide are present in the wastewater. Turbulence will release sulfide from the stream, generating odors and potentially deteriorating the structure. If drops must be used under such conditions, construction materials must be selected based on anticipated corrosion problems. To avoid odors and downstream corrosion, mechanical ventilation should be used to move air from downstream sections back to the drop structure. Sewer ventilation is discussed in Section 5.3.

### *5.2.4 Junctions and Transitions*

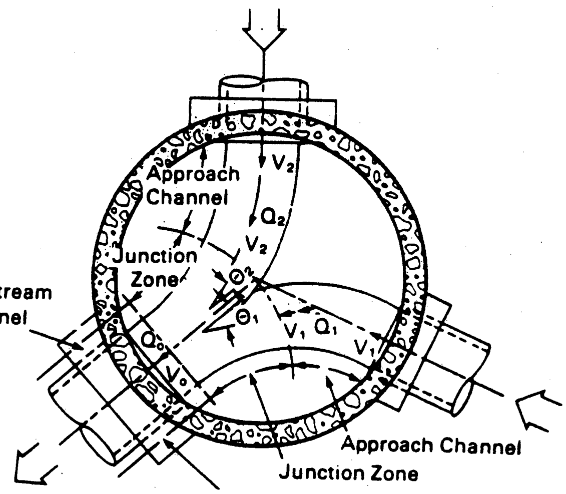
Sewer line junctions and transitions require special consideration because they offer an opportunity for both solids deposition and the release of dissolved sulfide. For aerobic wastewater, the major goal of junction design is to provide smooth transitions with minimum turbulence between incoming and outgoing lines so as to prevent eddy currents or low velocity points that will permit deposition of solids.

Design of junctions is more critical for sewers conveying septic wastewater, and special precautions must be taken to streamline the junction to minimize turbulence. Major factors that create turbulent conditions are:

1. Abrupt changes in grade between upstream and downstream sewer lines.
2. Large differences in velocity between two or more upstream sewer lines entering the same manhole.
3. Acute angles between upstream and downstream lines.
4. Large changes in flow between two or more upstream sewer lines that may be caused by upstream pumping or daily flow variation between different sewer service areas.
5. Large differences in flow between a trunk line sewer and tributary collector sewers.

A typical streamlined junction is shown in Figure 5-6.

**Figure 5-6. Streamlined junction (5).**




For one or more of the preceding conditions, turbulence will be minimized when the energy loss through the transition is minimum. This will be achieved when the following conditions are met (5):

1. The angle of convergence of the channels within the junction zone ($\theta_1$ and $\theta_2$) is as small as possible.
2. The channels are constructed so that the lateral momentum ($QV_1 \sin \theta_1$ and $Q_2V_2 \sin \theta_2$) of each of the incoming lines is reduced by the channel geometry before convergence of the two streams.
3. Velocity changes at the junction occur gradually.

### *5.2.5 Pumping Stations*

The design of pumping stations is a critical element of sanitary sewer collection systems. Ideally, pumping stations should be designed so as not to increase the total sulfide generation potential of the collection system. This is often difficult, however, since contemporary design practice for pumping stations requires some wet-well storage of wastewater plus retention in the force main. When supplementary aeration is not provided, both of the above conditions will tend to increase the potential for sulfide generation by increasing the total residence time in the system, and by increasing the contact time of the wastewater with sulfide-generating slimes within the force main and the wet-well surfaces. Potential also exists for sulfide generation from solids deposition in the wet well if the wet-well design does not contain adequate bottom slopes and suction piping arrangements for their continuous removal.

Pumping stations may be generally classified as continuous or intermittent, depending chiefly on the size of the tributary sewer system and average and maximum design flow rates. Of the two, the intermittent pumping stations have a much greater potential for sulfide generation than the continuous stations, where at least the minimum flow is pumped continuously and wet-well detention times are less.

For the smaller intermittently pumped stations, the most common design practice is the provision of a wet well equipped with on-off pumping controls whereby a single pump is activated by a high level switch and pumps at a constant rate until the level of sewage in the wet well is reduced to a predetermined level. Higher wet weather flows are accommodated by a second pump activated by a level control. Since the wet well storage and pumping schedules are generally established for average design flow conditions, the residence time in both the wet well and force mains is often excessive during low flow periods, especially in the early part of the system's design lifetime.

The volume of the wet-well storage provided depends on the peak and average flows and the minimum duty cycle of the pumping system. Many of the smaller pumping applications within a size range of 380 to 11,350 $m^3/d$ (0.1 to 3.0 mgd) utilize package pumping stations. Two pumps are normally provided, with a single pump sized to accommodate peak flow conditions. Duty cycles (time between successive starts) are typically 15 to 20 minutes, with minimum pumping times of 2 to 5 minutes. This design approach results in effective wet-well detention times of 5 to 15 minutes and total detention times of 7 to 20 minutes under average flow conditions. This may lead to excessive detention times and possible sulfide generation during low flow periods. Pomeroy indicates that significant sulfide generation will not occur in wet wells with detention times of less than 2 hours (1).

Wet wells should be as small as possible to minimize the potential for sulfide generation. A maximum wet-well design detention time of 30 minutes or less for all but the larger pump stations is recommended. The wet well should further be designed to avoid the accumulation of solids.

Wet-well detention times in larger pump stations equipped with variable speed pumps or with a combination of constant speed and variable speed pumps are generally sufficiently short to avoid sulfide generation.

Pump station wet wells are often the site of sulfi release when upstream DO levels are inadequat Alternatives for sulfide control in pump stations ar 1) wet-well aeration; 2) chemical addition; 3) cc lection and treatment of $H_2S$-contaminated air; 4) a bypassing to a downstream section of sewer; and injection of air or oxygen upstream in the force mai Wet-well aeration is effective in oxidizing dissolve sulfides, but can cause release of $H_2S$ by air strippin Short detention times in wet wells are insufficient achieve sulfide oxidation, while longer detentic times (>1 hour) may be adequate for complet oxidation. Wet-well aeration has the added advantag of temporarily increasing DO levels to prevent reduce sulfide generation in downstream force main Currently, package pump station manufacturers c not include wet-well aeration as a part of the standard design, but some provide a mixing valv from the discharge side of the pump to the wet well t provide increased mixing.

Wet-well aeration is a sulfide-control alternative tha should be considered when excessive wet-we detention times must be provided and when th incoming wastewater exhibits DO, BOD, and OR levels conducive to sulfide generation. This method i not recommended where significant sulfide (>0. mg/l) is present in the incoming wastewater. An OR level of +100 millivolts has been used as th minimum design ORP for pump stations in a syster design for Honolulu, Hawaii, to prevent sulfid generation in the downstream portions of the syster (7). The target ORP level is dependent on the individua wastewater characteristics and the downstrean collection system network.

All lift station designs should include an evaluation o the influent wastewater conditions, and of the impac of wet-well storage and force main sulfide-generatior potential on downstream segments. In many cases air or oxygen injection into the force main should be considered as an alternative to wet-well aeration This method eliminates the problem of $H_2S$ release has the flexibility of providing the increased oxygena tion capability where it is needed, and offers a highe and simpler level of control. Air and oxygen injectior for sulfide control in collection systems is discussec in detail in Chapter 3.

The design of pump stations must also include ar analysis of the sulfide generation potential of force mains. Sulfide generation within the force main is related to the wastewater characteristics, including DO present, EBOD, temperature, and sulfate concentration. Thistlethwayte has postulated that the concentration of sulfide buildup in a force main is proportional to $(L/D)(BOD)(SO_4)$ for continuously pumped systems, and that buildup for intermittently pumped systems is proportional to $(L/D)(BOD)(SO_4)(1.64)(V_c/V_i)$ where L is the sewer length, D is the sewer diameter, $V_c$ is the velocity of a continuously pumped system, and $V_i$ is the average velocity for an intermittently pumped system (5). It should be noted that other researchers have indicated that sulfate concentration does not limit sulfide buildup except at very low concentrations. Based on the work of Thistlethwayte, it was found that the total mass of sulfide generation was approximately equal in a given time period for a particular wastewater regardless of pumping cycles, but that the concentration of sulfide generated by intermittent pumping for certain pumping cycles could be several times that of a continuously pumped system. This finding is critical for downstream situations where the intermittent discharge of sulfide from force mains could create significant localized odor and corrosion problems. Since sulfide generation within force mains is due primarily to surface slime, larger force main sizes reduce the sulfide generation potential for a given design flow and wastewater characteristics, since they result in a smaller surface-area to cross-sectional-area ratio. The selection of force main size is normally made based on a cost analysis of increased pumping cost vs. the capital cost of the force main. For situations in which sulfide generation potential exists within the force main, a larger size force main may be warranted to reduce sulfide generation and subsequent sulfide control costs. Since most force mains may sometimes operate under conditions that produce sulfide, the discharge should be designed to minimize turbulence. Some circumstances may require special ventilation, sealing or collection and treatment of the odorous air.

An air bypass can often be used to shunt air around a pump station to control odor release from the wet well. This involves the use of a sealed wet well as shown in Figure 5-7 (1). An air bypass line is constructed between the wet well and the closest upstream gravity manhole. In some cases, this distance may be so long as to make this approach impractical. It is suggested that the air bypass line be approximately two-thirds of the force main pipe diameter (1). This approach would be especially applicable when a downstream gravity flow segment has significant reaeration potential and the force main distances are short. When significant sulfide generation is anticipated, separate air collection and treatment may be warranted. Separate off-gas treatment is discussed in Chapter 4.

In cases where pumps are designed for lift only and the wastewater is not discharged into a pressure main, it may be desirable to consider use of an air lift pump. Air lift pumps are typically used only for low flow applications, where their ease of maintenance and reliable operation outweighs their low efficiency, which is limited to about 15 percent. However, economics of an air lift pump may improve substantially when considering that it serves two functions, pumping and aeration. Figure 5-8 shows a schematic diagram of a lift station employing an air lift pump with an air bypass line around the lift station (1). To eliminate a net discharge of air, the compressor takes air from the bypass connecting the sealed wet well and the downstream sewer.

The design of wet-well aeration systems, air or oxygen injection into force mains, and chemical addition is discussed in Chapter 2.

Figure 5-7. Pump station with an air bypass (1).

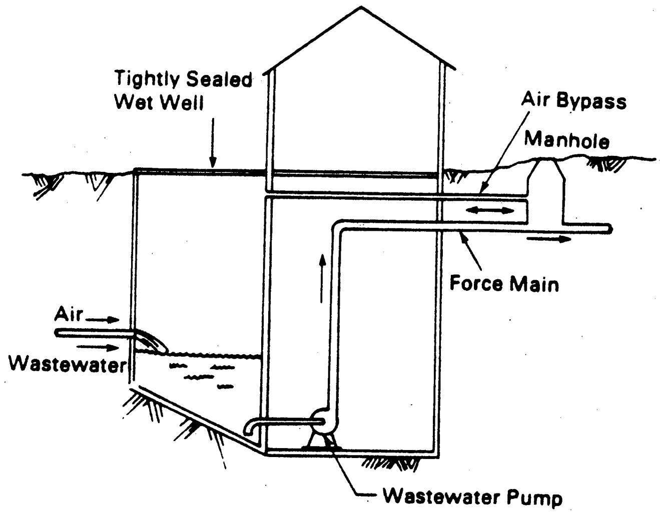
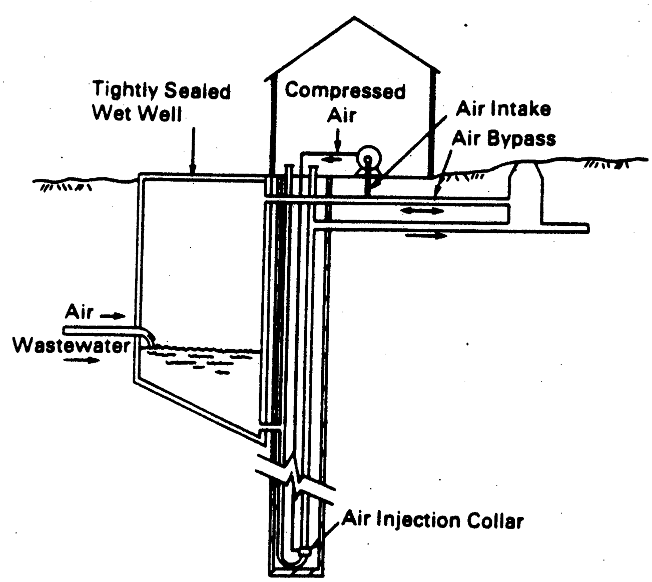



Figure 5-8. Air-lift pump station (1).



### *5.2.6 Siphons*

Siphons, also called inverted siphons or depressed sewers, are used to convey wastewater under streams or highways, conduits or other obstructions to the normal sewer grade line, and to regain as much elevation as possible after passing the obstruction. Siphons are normally limited to pipe sizes greater than 20-cm (8-in) diameter. Sewage in siphons is under pressure, since the conduits are below the hydraulic grade line. Because the siphon remains full even during periods of no flow, it is a potential site of significant sulfide generation and odor release.

Methods of controlling sulfide generation that would be applicable to siphons were discussed in Chapter 3. These techniques include improving the oxygen balance by air or oxygen injection, or by addition of chemicals to oxidize or precipitate the sulfide or prevent its formation.

Siphon design must consider the potential for odor release. Positive pressure develops in the atmosphere upstream of the siphon due to the downstream movement of air induced by the wastewater flow. Air thus tends to exhaust from the manhole at the siphon inlet and may escape in large amounts from small openings, such as pick holes in manhole covers. At less than maximum flow, wastewater dropping into the inlet may cause turbulence and odor release.

One technique that has been successfully used to minimize odor release at siphons is the use of air jumpers. These are pipes that take the air off the top of the inlet structure and convey it to the end of the siphon. In most cases, air jumpers run parallel to the siphon, although the pipe can be suspended above the hydraulic grade line. Provisions should be made to drain the air jumper to periodically remove accumulated condensate. Usually, the diameter of the air jumper pipe is approximately one-half that of the siphon (6). Solids deposition is another potential problem and siphons should normally be designed for velocities of 0.9 m/s (3.0 ft/s) to prevent solids deposition and subsequent odor generation. In some cases, multiple siphon lines are installed to ensure adequate velocities during the early design lifetime of the system. In these instances, the unused sewer line may be used as the air jumper line during the early design period when flow is small and sulfide generation may be a problem.

## 5.3 Ventilation of Sewers

### *5.3.1 Objectives of Ventilation*

Ventilation of sewers is often undertaken for a variety of reasons. For the most part, only the control of odors is practically achievable with ventilation. Some of the reasons ventilation has been attempted are discussed here.

#### 5.3.1.1 Increasing the Oxygen Content of th Sewer Atmosphere

The oxygen content of the sewer atmosphere doe not change significantly as a result of the septicity c the wastewater. In partially filled sewers, rise and fa of the liquid level results in displacement an replacement of air, and there is normally a down stream flow of air due to a drag effect between th air-sewage interface. Oxygen concentrations in suc sewers are rarely less than 90 percent of normal. I oxygen concentrations are above 90 percent o normal, ventilation is unlikely to make a significan difference in the oxygen balance of the stream.

#### 5.3.1.2 Reducing the Atmospheric $H_2S$ Concentrations

Although it would seem feasible to ventilate sewers to reduce the atmospheric sulfide concentrations and thus control corrosion, this approach has little practical value. In order to have measureable results, complete replacement of the sewer atmosphere with fresh air would be required at frequent intervals. Even if this approach were economical, there would be the problem of disposal of large volumes of malodorous air.

#### 5.3.1.3 Drying the Walls of Sewers and Other Structures

The oxidation of hydrogen sulfide gas to sulfuric acid does not occur if the surface is dry, since moisture must be present for bacterial oxidation of $H_2S$. Ventilation has been used with the objective of drying sewer walls. Thistlethwayte estimated that when the relative humidity of the sewer atmosphere exceeds 80 to 85 percent, sufficient moisture will be present on the walls to support bacterial activity (5). Thistlethwayte also proposes a design procedure for ventilation of sewers to control humidity, but indicates that in most cases this approach is not practicable. This is due to the rapid increase in relative humidity of ventilation air with flow along the sewer, the large number of ventilation stations required, and the significant increase in operation and maintenance costs. Pomeroy also indicates that this approach is impractical for year-round protection for even typical sewer distances between manholes (1).

#### 5.3.1.4 Preventing Lethal Atmospheres

Portable fans or blowers are often used to ventilate manholes before workers enter. This is acceptable practice for localized conditions, provided other normal safety procedures are followed. However, it is questionable as to whether this practice would provide a safe environment between manholes. It is not feasible to ventilate large sections of a sewer system sufficiently to assure a safe environment for sewer workers.

**5.3.1.5 Preventing Explosive Atmospheres**
Explosions in sewers generally result from the presence of large amounts of volatile hydrocarbons or from leaking natural gas mains. Only under very unusual conditions do explosions result from accumulation of sewer gases. Because of the unpredictable causes of explosions and the conditions under which they occur, it is unlikely that ventilation could assure protection from explosions in a wastewater collection system.

**5.3.1.6 Controlling Odor Emissions**
Sewer ventilation can withdraw malodorous air at one point in order to prevent odor emissions at other locations. Normally, contaminated air must undergo treatment by one or more of the techniques discussed in Chapter 4. Ventilation is often practiced at wastewater treatment plants, where air is withdrawn at the downstream terminus of the sewer (plant headworks) and either treated separately or piped to existing biological stabilization processes for removal of odors. Although most other possible objectives have not been achieved by practical levels of ventilation alone, control of odor emissions can be effectively served by continuous ventilation.

***5.3.2 Methods of Ventilation***
Ventilation of a sewer can occur through both natural and mechanical means. Virtually all sewers incorporate some method of natural ventilation. Mechanical ventilation, on the other hand, is normally employed only in response to complaints of odor emissions from a portion of the collection system following the original design. The two methods are discussed below.

**5.3.2.1 Natural Ventilation**
Collection systems in the United States do not normally incorporate special vents or hardware to assist in natural sewer ventilation. Rather, manholes and building vents are generally considered adequate to keep sewers sufficiently ventilated (6).

Natural ventilation occurs from the following forces (5)(8).

1. Change in barometric pressure along the sewer
2. Wind velocities past vents
3. Frictional drag of wastewater on sewer air
4. Rise and fall of the wastewater level in the sewer
5. Relative density differences of sewer air and outside air

The degree of natural ventilation which occurs in a sewer is difficult to predict, since fluctuations in the above variables may change both the direction of movement and velocity of the air contained in the sewer.

Whereas no special provisions are normally made to enhance natural ventilation of sewers in the United States, special ventilation systems are routinely incorporated into sewer designs in the United Kingdom and Australia (5). The reason for this is that collection systems designed in the United Kingdom and Australia have typically incorporated "boundary traps" or "running traps" at building sewers or house laterals, which effectively prevent the transfer of air between the sewer and building vents. Since the building vent is no longer a source of ventilation air, induct and educt stacks are placed at various locations in the collection system to allow air movement into and out of the sewer. Research on natural sewer ventilation systems is discussed in References 7 and 8, and detailed design procedures for such ventilation systems are presented in Reference 4.

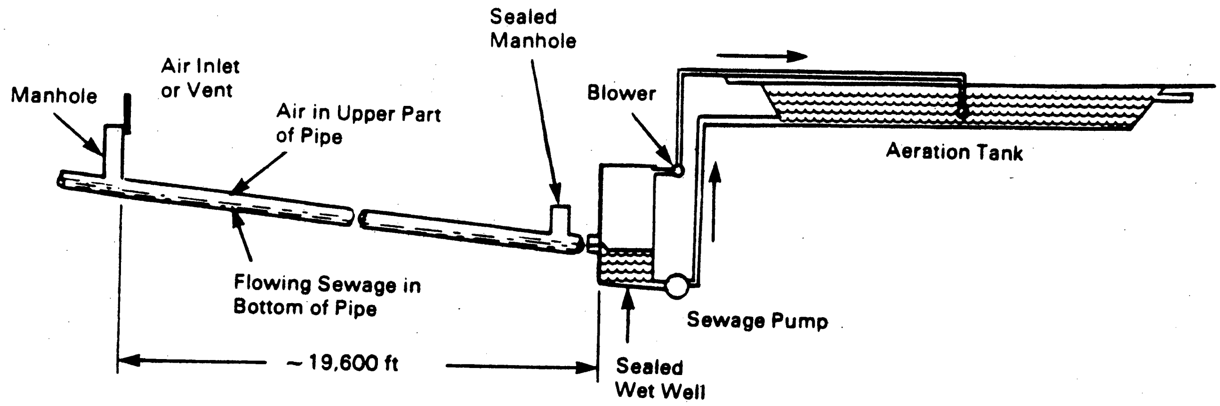
**5.3.2.2 Mechanical Ventilation**
Mechanical ventilation may be employed where a constant velocity and direction of air flow is desired. This may be necessary where odor emissions from sewers must be controlled, as in residential neighborhoods, or where hydraulic conditions that occur in siphons or surcharged sewers result in stagnant air pockets with reduced oxygen contents. Mechanical ventilation may also be employed at headworks of wastewater treatment plants in order to convey malodorous sewer gases to odor control systems.

Figure 5-9 shows two examples of the use of mechanical ventilation for odor control in Austin, Texas (10). At Williamson Creek, odors escaping from septic wastewater entering the wet well necessitated sealing of the wet well and upstream manhole to allow withdrawal of air from 5,980 m (19,600 ft) of 106-cm (42-in) diameter concrete outfall line. A 7.1-$m^3$/min (250-scfm) blower was used to remove odorous gases from the sewer and discharge them to an aerated stabilization pond. This approach was successful in controlling odors from the system.

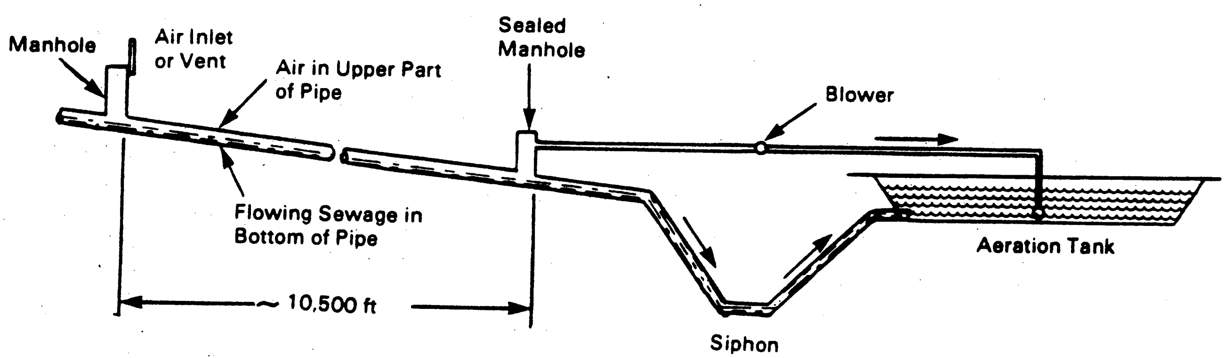
A similar approach was used for the Walnut Creek system. This was a total gravity system which included a siphon for conveying wastewater under Walnut Creek. Two 14.2-$m^3$/min (500-scfm) blowers were used to remove odorous gases from 3,200 m (10,500 ft) of concrete sewer at a sealed manhole upstream of the siphon. The blower discharged the gases through air lift pumps in the aeration basin of the treatment plant to achieve better mixing of the tank contents and absorption and oxidation of the odorous components of the gas in the aerated liquid.

Ventilation of pumping stations is part of normal design procedures for these structures. A minimum of 12 air changes per hour is recommended for continuously ventilated wet wells and 30 air changes per hour for intermittently ventilated wet wells. A minimum of 6 air changes per hour is recommended for continuously ventilated dry wells and 30 air

Figure 5-9. Forced draft ventilation for odor control, Austin, TX (9).




a) Ventilation System at Williamson Creek, TX




b) Ventilation System at Walnut Creek, TX

changes per hour for intermittently ventilated dry wells and other below grade structures (11).

## 5.4 Selection of Materials

Materials selection is a critical aspect in design of wastewater collection systems in which sulfide generation is likely to pose problems. The additional expense of using materials with greater degree of corrosion resistance may be justified by the cost savings for replacement or rehabilitation of deteriorated structures at some later date. The following discussion describes the various materials used in collection systems, with particular emphasis on the corrosion-resistant properties of each material.

### *5.4.1 Pipe Materials*

If sulfide is expected to be present in sufficient quantities to cause corrosion, consideration must be given to the use of pipe materials with higher degre of corrosion resistance. Design considerations selecting such materials are (1):

1. Availability of the materials in the pipe siz required
2. Minimum and maximum levels of sulfide e pected in the wastewater
3. Factors other than acid resistance of the pip (abrasion resistance, stress-corrosion resis tance, load-bearing strength, and other durabi ity considerations)
4. Hydraulic characteristics of the materials und conditions of actual use
5. Other advantages or disadvantages of th material (ease of installation, resistance t infiltration, flexibility, etc.)
6. Expected future service requirements
7. Relative costs vs. expected service lifetimes c various kinds of pipe

#### 5.4.1.1 Concrete Pipe

Concrete is one of the most common materials used in construction of sewer pipe, and is virtually the only material used for large diameter trunk sewers.

Several alternatives are available to extend the design lifetime of concrete pipe in corrosive atmospheres found in sewers. These include: 1) specification of calcareous aggregate, which increases the overall alkalinity of the concrete; 2) specification of additional wall thickness to serve as sacrificial material; and 3) use of liners or coatings with high degrees of corrosion resistance on the interior pipe walls.

Alkalinity of the concrete pipe and the thickness of concrete cover over the reinforcing steel have been used in the development of the "life factor" equation (12):

$$(A)(z) = 0.45\ k\ \phi_{sw}\ L \qquad (5\text{-}4)$$

where,

$(A)(z)$ = life factor = product of alkalinity [expressed as a weight fraction; i.e., alkalinity as ($CaCO_3$) as fraction of cured pipe weight] and thickness of allowable concrete loss (in)

$k$ = coefficient of efficiency for acid reaction (see Equation 2-30)

$\phi_{sw}$ = flux of $H_2S$ to the pipe wall, g/m²/hr (see Equation 2-20)

$L$ = desired design lifetime, years

This equation is useful in that, if the $H_2S$ flux is calculated based on assumed conditions, the desired service life of the pipe can be entered and a life factor computed, which allows flexibility in selecting various combinations of pipe thickness and alkalinity of the concrete.

Example:

Assume $L$ = 50 years

$\phi_{sw} = 0.03$ g/m²/hr

$k = 0.7$

$(A)(z) = 0.45\ k\ \phi_{sw}\ L = (0.45)(0.7)(0.03)(50) = 0.47$

This life factor could theoretically be met by numerous combinations of alkalinity and wall thickness, examples of which are shown below.

| Aggregate | Alkalinity of Concrete(A) | Concrete Cover (z) | (A)(z) |
|---|---|---|---|
| | weight fraction | in | |
| Granitic | 0.2 | 2.4 | 0.48 |
| 50-percent Calcareous | 0.50 | 1.0 | 0.50 |
| 100-percent Calcareous | 0.85 | 0.6 | 0.51 |

A manufacturer can thus meet the required life factor by using the combination of alkalinity and wall thickness that is most economical and suitable to the expected use and to the production process.

The alkalinity of concrete varies with the cement content and type of aggregate. Ranges of alkalinity (weight fraction) for concrete pipe containing 352 kg cement/m³ (594 lb/cu yd) are shown below for various aggregates:

| | |
|---|---|
| Granitic aggregate: | Alkalinity = 0.18 to 0.22 |
| 50-percent calcareous aggregate: | Alkalinity = 0.4 to 0.6 |
| 100-percent calcareous aggregate: | Alkalinity = 0.8 to 0.9 |

Procedures for obtaining interior wall cores of concrete pipe and for determining alkalinity of the samples are described in References 13 and 14.

Alkalinity of the interior wall of concrete pipe will also vary with the method of manufacturing. Centrifugally spun pipe generally has a higher interior wall alkalinity than cast pipe due to the migration of cement toward the interior wall during production (14).

It should be noted that not all concrete pipe manufacturers have ready access to calcareous aggregates. Most manufacturers should be able to meet life factor, (A)(z) design specifications through a combination of concrete alkalinity and wall thickness.

#### 5.4.1.2 Asbestos Cement Pipe

Asbestos cement pipe is subject to attack by sulfuric acid. Because the cement content is higher than for reinforced concrete pipe, the alkalinity may also be higher, depending on the type of aggregate used. However, corrosion of asbestos cement pipe immediately begins to degrade the structural section of the pipe, as opposed to corrosion of reinforced concrete pipe in which the concrete cover over the reinforcing steel is degraded before the structural integrity of the pipe is affected.

Although variability in the alkalinity of asbestos cement pipe is limited, the life factor design approach can be employed to determine required thickness. Alkalinity of asbestos cement pipe is typically in the range of 0.5 to 0.6 (12).

It should be noted that asbestos cement pipe is banned in many areas, and is generally not available in the United States because of the known health effects of asbestos fibers.

#### 5.4.1.3 Vitrified Clay Pipe

Vitrified clay pipe is immune to attack by sulfuric acid and most volatile industrial waste products, and as such is a suitable material for use where high sulfide concentrations are expected. Elastomeric jointing materials, which are resistant to attack by many corrosive materials, should be used with the vitrified clay pipe. Properly laid and jointed, vitrified clay pipe will remain serviceable for a very long time if not disturbed by external forces. Vitrified clay pipe is available in sizes ranging from 10 cm (4 in) to 107 cm (42 in); the larger sizes may not be available in all parts of the country.

#### 5.4.1.4 Reinforced Plastic Mortar Pipe

Reinforced plastic mortar pipe is constructed of polyester resin mixed with sand and reinforced with fiberglass. The resulting product is not subject to sulfuric acid attack unless the glass fibers are exposed due to damage during handling or deflections of the pipe. If the fibers are exposed, acid can creep along the fibers and react with impurities in the fibers. The oldest sewer constructed of reinforced plastic mortar pipe is a trunk sewer installed in San Jose, California in 1966 (1)(12).

#### 5.4.1.5 Homogeneous Plastic Pipe

Polyvinyl chloride (PVC), acrylonitrile-butadiene-styrene (ABS), and polyethylene (PE) are pipe materials resistant to sulfuric acid attack and thus suitable for use where high sulfide concentrations are expected. Care must be given to bedding and backfill to keep pipe deflections to an acceptable minimum (1)(12). ABS pipe is very susceptible to stress corrosion.

#### 5.4.1.6 Steel Pipe

Steel pipe is subject to corrosion by sulfuric acid as well as by $H_2S$ in the presence of oxygen when the sewer is flowing partially full. The oxidation product, iron sulfide, can accumulate to an extent that the hydraulic capacity and the structural integrity of the line are significantly reduced.

#### 5.4.1.7 Ductile Iron Pipe

Ductile iron pipe has replaced gray cast iron pipe for use in wastewater collection systems. Gray cast iron pressure pipe is no longer manufactured in the United States.

Ductile iron pipe normally lasts longer than steel pipe due to the increased wall thickness. However, iron is subject to corrosion in the presence of oxygen as is steel, and the bulky corrosion products may accumulate and restrict the cross-sectional area of a pipe and affect the structural integrity of the pipe.

When iron pipe is corroded by $H_2S$ gas, sulfuric acid, or other agents, the process proceeds by graphitization, which involves dissolution and removal of the iron crystals, leaving behind non-metallic components such as graphite, carbides, silicides of iron, and corrosion products. Although the pipe may appear be in good condition, its structural strength is ofte greatly reduced (15).

### *5.4.2 Pipe Linings and Protective Coatings*

Many different types of linings and coatings hav been used in attempts to protect pipe from corrosic due to wastewaters containing sulfides. Unfortu nately, success with these materials has been qui variable. The problem is in achieving a sealed linir that is firmly affixed to the interior pipe wall ar which has no defects, pinholes, or constructic damage that would allow penetration of acid to th pipe. Such defects can result in localized corrosio occurring at a greater rate than if the acid attack wer distributed over the total pipe surface. Acid, pene trating through pinhole-sized defects, attacks th underlying material, and the accumulation of expar sive corrosion products eventually ruptures the linin or coating, allowing greater acid penetration an progressive deterioration of the pipe. Coatings can b painted, sprayed, or troweled onto the interior surfac of the pipe, and linings may be applied as preforme sheets or panels during manufacture of the concret pipe.

#### 5.4.2.1 PVC Liners

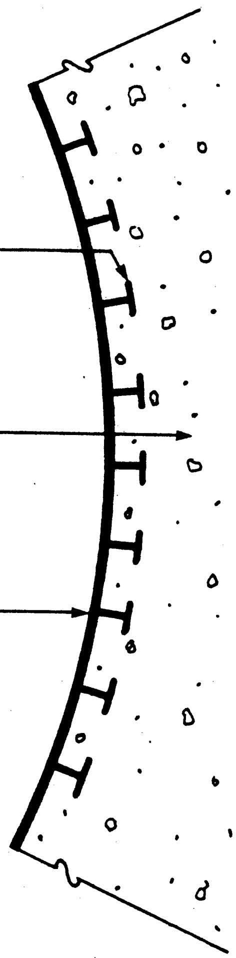
One of the few lining systems which has been use successfully for long-term protection of concrete is PVC liner mechanically attached to the concrete. Th liner consists of sheets of plasticized PVC approxi mately 1.5-mm (1/16-in) thick with T-shaped key running longitudinally on one face. The sheets ar fastened to the forms, key side in, before pouring o the concrete during manufacture of the pipe. In th finished pipe, the keys are firmly imbedded in th concrete. The PVC sheets are heat-welded at the pip joints to produce a completely sealed liner. A sche matic diagram of a T-lock PVC liner for concrete pip is shown in Figure 5-10 (16).

Some problems have arisen in the installation of suc liners in cast-in-place concrete pipe because of th difficulty in imbedding all the keys. No such problem have been reported for factory made pipe. Althoug PVC liners may be subject to damage from very hig turbulence or from mechanical cleaning tools, prope design and operation can overcome such problem (1). In California, PVC sheet lining has been success fully used for concrete sewer pipe protection for ove 30 years (17).

#### 5.4.2.2 Vitrified Clay Liner Plates

Vitrified clay liner plates mechanically locked tc concrete pipe have also been used. However, porosity of the clay allowed acid to diffuse into the concrete softening and expanding it, which resulted in crackinç of the plates and breaking of the lugs which lock the

Figure 5-10. T-lock PVC liner for concrete pipe.




plates to the interior wall of the pipe (1)(18). This product is no longer available in many areas.

**5.4.2.3 Thick Film Coal Tar/Epoxy Coatings**

One of the few pipe coatings for which long-term performance data are available is the thick film coal tar/epoxy coating. Such coatings are spray-applied either during or after manufacture of the pipe, but prior to pipe installation. Although many coatings are applied in relatively thin films <2.5 mm (10 mil), thick film coal tar/epoxy coatings are generally applied with a minimum thickness of 10 mm (40 mil). In some cases, film thicknesses of up to 25 mm (100 mil) are specified. Coal tar/epoxy coatings are used for both metal and concrete pipe.

For successful long-term performance of thick film coal tar/epoxy coatings, the following conditions must be met:

1. Adequate surface preparation—sandblasting of the surface to remove all foreign materials and contaminants; removal of dust.
2. Adequate film thickness—minimum film thickness of 10 mm (40 mil).
3. Adequate quality assurance procedures, including:
   a. Checks on wet film as applied
   b. Checks on dry film thickness
   c. Low voltage holiday detection on 100 percent of barrel surface
   d. Hanging-weight adhesion tests

**5.4.2.4 Cement Mortar Liners**

Cement mortar is often used as a liner for iron or steel pipe in wastewater applications. For conditions in which sulfide-induced corrosion may present a problem, additional liner thickness and/or alkalinity of the cement may be specified. The life factor design approach can be used to achieve a desired lifetime of the cement mortar lining. Alkalinities of mortar used in lining of ferrous pipe are typically 0.4 to 0.5 (12).

**5.4.2.5 Other Pipe Lining Coatings**

Another alternative lining material is type 3 lb L stainless steel sheeting with a thickness of 0.5 to 0.6 cm (0.18 to 0.25 in). These sheets may be used where PVC sheet liners may be subject to mechanical damage.

Numerous coatings are available for sewer pipe. Some of the more common materials not previously discussed include asphaltic compounds, polyethylene, and polyurethane. Asphaltic compounds have not proved to be successful in sewers in which $H_2S$ is present. Volatile materials present in the wastewater can dissolve the coating, and scratches, defects, or pinholes allow acid to migrate to the pipe. Long-term field experience with polymeric materials, such as polyethylene and polyurethane, is limited.

***5.4.3 Construction Materials for Appurtenances***

In designing a wastewater collection system to avoid sulfide problems, selection of pipe materials is of paramount concern. However, the design engineer must also consider selection of materials for sewer appurtenances such as manholes, transition structures, and drops.

If relatively high sulfide concentrations are expected in the wastewater, such appurtenances may promote turbulence and release of $H_2S$, which can result in $H_2S$ gas and sulfuric acid attack on both pipe and appurtenances. An example of this type of occurrence is described below.

In Port St. Lucie, Florida, a 10-cm (4-in) PVC pressure pipe carrying septic tank effluent from approximately

200 homes discharged into the concrete manhole of a larger diameter gravity sewer conveying raw wastewater. The septic tank effluent contributed approximately 20 percent of the total flow, and contained dissolved sulfide concentrations in excess of 10 mg/l. After approximately 8 years of service, severe deterioration of both the concrete manhole and the cast iron manhole cover was observed. This was attributed to the turbulence at the junction of the two streams, which released $H_2S$ gas to the sewer atmosphere. The concrete manhole was replaced with one fabricated from fiberglass, and a drop pipe was installed to reduce turbulence. Although no deterioraton of the fiberglass manhole has been observed, evidence of corrosion has been noted at the next concrete manhole downstream.[1]

It is, therefore, necessary to carefully consider materials selection for all components of a wastewater collection system, including manholes, junctions, and drops, in which the presence of $H_2S$ gas and sulfuric acid poses a potential corrosion problem.

## 5.5 References

When an NTIS number is cited in a reference, that reference is available from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
(703) 487-4650


1. *Process Design Manual for Sulfide Control in Sanitary Sewerage Systems.* U.S. Environmental Protection Agency, Technology Transfer, PB-260 479/AS, October, 1974.
2. Metcalf and Eddy, Inc. *Wastewater Engineering.* McGraw-Hill, New York, NY, 1972.
3. Yao, K.M. *Functional Design of Sanitary Sewers.* JWPCF 48 (7): 1772-1778, 1976.
4. *Design Manual for Sulfide and Corrosion Prediction and Control.* American Concrete Pipe Association, Vienna, VA, 1984.
5. Thistlethwayte, D.K.B. *The Control of Sulphides in Sewerage Systems.* Ann Arbor Science, Ann Arbor, MI, 1972.
6. *Design and Construction of Sanitary and Storm Sewers.* Manual of Practice No. 9, Water Pollution Control Federation, Washington, DC, 1970.
7. Yogi, D.R., R.L. Smith, and N.C. Burbank, Jr. *Hydrogen Sulfide, Control in Sewers Containing Brackish Water—Honolulu, A Case Study.* sented at the 54th Annual Conference, W Pollution Control Federation, Las Vegas, October, 1981.
8. Pescod, M.B. and A.C. Price. *Major Facto Sewer Ventilation.* JWPCF 54 (4): 385- 1982.
9. Pescod, M.B. and A.C. Price. *Fundamenta Sewer Ventilation as Applied to the Tyne Sewerage Scheme.* Water Pollution Contrc (1): 17-33, 1981.
10. Ullrich, A.H. *Forced Draft Ventilation Prot Concrete Sewer Pipe, Controls Odors.* W and Wastes Engineering (4): 52-55, 1968.
11. *Recommended Standards for Sewage Wc* Great Lakes-Upper Mississippi River Boar State Sanitary Engineers, Health Educa Service, Albany, NY, 1978.
12. Kienow, K.K. and R.D. Pomeroy. *Corros Resistant Design of Sanitary Sewer Pipe.* W and Sewage Works, Reference Number, F 13, 1979.
13. *Concrete Pipe Handbook.* American Conc Pipe Association, Vienna, VA, 1981.
14. Kienow, K.K. *Protecting Reinforced Conc Pipe Sanitary Sewers.* Water and Sewage Wc 122 (10): 94-97, 1975.
15. Pomeroy, R.D. *Corrosion of Iron and by Sulfic* Water Works and Sewage, April, 1945.
16. Spindel, E. *Methods of Preventing Corrosio Sewerage Systems.* Corrosion 12 (3), 1956.
17. Graham, R.E. *San Diego's PVC Sewer Lin Fight Corrosion After 20 Years.* Water ε Sewage Works 116 (5): 168-171.
18. Pardee, L.A. and F.G. Studley. *Concrete Sev Protection.* Water and Sewage Works, Ap 1957.


[1] *Personal Communication: Patricia H. Lodge, General Development Utilities, Inc.*