CALIFORNIA
DEPARTMENT OF TRANSPORTATION

manual change transmittal

TITLE DIVISION OF DESIGN HIGHWAY DESIGN MANUAL SIXTH EDITION – CHANGE 11/02/09	APPROVED BY TERRY L. ABBOTT, Chief	NO. Date Issued: 10/30/09 Page 1 of 3
SUBJECT AREA Table of Contents; List of Figures; List of Tables; Chapters: 820-850; and, Index	ISSUING UNIT DIVISION OF DESIGN	
SUPERCEDES SEE BELOW FOR SPECIFIC PAGE NUMBERS	DISTRIBUTION **ALL HOLDERS OF THE 6TH EDITION, HIGHWAY DESIGN MANUAL**	

The Table of Contents; List of Figures; List of Tables; Chapters: 820, 830, 840, 850; and the Index of the Sixth Edition, Highway Design Manual (HDM) have been revised. The revisions and changes are described herein in the summary below with change sheets available on the Department Design website at: http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm. These revisions and changes are effective November 2, 2009, and shall be applied to on-going projects in accordance with HDM Index 82.5 – Effective Date for Implementing Revisions to Design Standards.

HDM Holders are encouraged to use the most recent version of the HDM available on-line at the above website. Should a HDM Holder choose to maintain a paper copy, the Holder is responsible for keeping their paper copy up to date and current. Using the latest version available on-line will ensure proper reference to the latest design standards and guidance. If you would like to be notified automatically of any significant changes or updates to the HDM, go to http://www.dot.ca.gov/hq/oppd/hdm/hdmlist.htm.

In addition to the revisions described herein, the original contents of Chapter 850 have been completely reorganized and renumbered to follow a more logical progression. A summary of the most significant revisions are as follows:

Index 853.1 — **General, Page 850-11**
Overview of alternative pipe liner and pipe lining materials specifically intended for culvert repair.

Index 853.2 — **Caltrans Host Pipe Structural Philosophy, Page 850-11**
Establishes protocol for determining whether or not to rehabilitate the culvert and/or which method to choose.

Index 853.3 — **Problem Identification and Coordination, Page 850-11**
Provides guidance on how to determine the actual cause of the problem and with whom the Engineer should coordinate.

Index 853.4 — **Alternative Pipe Liner Materials, Page 850-11**
Discusses providing for alternative pipe liners to allow for optional selection by the contractor.

Table 853.1A — **Allowable Alternative Pipe Liner Materials, Page 850-12**
Table of allowable alternative pipe liner materials for culverts and drainage systems. This table also identifies the various diameter range limitations and whether annular space grouting is needed.

Table 853.1B	**Guide for Plastic Pipeliner Selection in Abrasive Conditions to Achieve 50 Years of Maintenance Free Service Life, Page 850-14** This table identifies the various diameter range and product limitations to achieve 50 years of maintenance-free service life in abrasive conditions.
Index 853.5	**Cementitious Pipe Lining, Page 850-12** Method for lining corroded corrugated steel pipes with concrete, shotcrete or mortar using a lining machine.
Index 853.6	**Invert Paving with Concrete, Page 850-13** Method to rehabilitate corroded and severely deteriorated inverts of CMP that are large enough for human entry.
Index 853.7	**Structural Repairs with Steel Tunnel Liner Plate, Page 850-15** Method to rehabilitate culverts in need of structural repair to accommodate all live and dead loads.
Index 855.2	**Abrasion, Page 850-20** Discussion of abrasion levels and tables to assist the designer in quantifying the abrasion potential of a site for alternative pipe or lining selection.
Table 855.2A	**Abrasion Levels and Materials, Pages 850-23 thru 805-26** Six abrasion levels have been defined with allowable pipe materials to assist the designer with material selection to achieve the required service life.
Table 855.2B	**Bed Materials Moved by Various Flow Depths and Velocities, Page 850-27** Guide to determine the maximum size of material that can be moved through a pipe.
Table 855.2C	**Guide for Anticipated Service Life Added to Steel Pipe by Abrasive Resistant Protective Coating, Page 850-28** Guide for estimating the added service life that can be achieved through coatings and invert paving of steel pipes based upon abrasion resistance characteristics.
Table 855.2D	**Guide for Anticipated Wear to Metal Pipe by Abrasive Channel Materials, Page 850-29** Guide for anticipated wear per year to metal pipe by abrasive channel materials to assist the designer with material selection to achieve the required service life.
Table 855.2E	**Relative Abrasion Resistance Properties of Pipe and Lining Materials, Page 850-29** Indicates relative abrasion resistance properties of pipe and lining materials to steel.
Table 855.2F	**Guide for Minimum Material Thickness of Abrasive Resistant Invert Protection to Achieve 50 Years of Maintenance-Free Service Life, Page 850-30** Guide to assist the designer with minimum material thickness selection to achieve 50 years of maintenance-free service life.
Index 855.4	**Protection of Concrete Pipe and Drainage Structures from Acids, Chlorides and Sulfates, Page 850-34** Discussion to assist the designer for protecting concrete pipe and drainage structures from acids, chlorides and sulfates.

Table 855.4A — **Guide for the Protection of Cast-In-Place and Precast Reinforced and Unreinforced Concrete Structures against Acid and Sulfate Exposure Conditions, Page 850-35**
Table 855.4A indicates cementitious material requirements and water content restrictions by acidity of soil or water.

Table 855.4B — **Guide for Minimum Cover Requirements for Cast-In-Place and Precast Reinforced Concrete Structures for 50-Year Design Life in Chloride Environments, Page 850-35**
Table 855.4B provides a guide for minimum concrete cover requirements for various ranges of chloride concentrations in soil and water for all precast and cast in place construction of drainage structures.

Index 857.2 — **Alternative Pipe Culvert Selection Procedure Using AltPipe, Page 850-58**
Instructions for using the web-based tool AltPipe to assist materials engineers and designers in the appropriate selection of pipe materials for culvert and storm drain applications.

Enclosures available on the Department Design website at: http://www.dot.ca.gov/hq/oppd/hdm/hdmtoc.htm.

Table of Contents

Table of Contents

Topic Number		Subject	Page Number

CHAPTER 850 - PHYSICAL STANDARDS

Table of Contents

CHAPTER 860 - OPEN CHANNELS

Table of Contents

CHAPTER 870 - CHANNEL AND SHORE PROTECTION - EROSION CONTROL

Table of Contents

Table of Contents

CHAPTER 1000 - BIKEWAY PLANNING AND DESIGN

Table of Contents

Topic Number		Subject	Page Number

List of Figures

List of Figures

List of Figures

List of Figures

List of Figures

List of Figures

List of Tables

List of Tables

List of Tables

List of Tables

List of Tables

(c) In steep sloping areas such as on hillsides, the overfill heights can be reduced by designing the culvert on a slope flatter than natural slope. However, a slope should be used to maintain a velocity sufficient to carry the bedload. A spillway or downdrain can be provided at the outlet. Outlet protection should be provided to prevent undermining. For the downdrain type of installation, consideration must be given to anchorage. This design is appropriate only where substantial savings will be realized.

Topic 824 - Culvert Type Selection

824.1 Introduction

A culvert is a hydraulically short conduit which conveys stream flow through a roadway embankment or past some other type of flow obstruction. Culverts are constructed from a variety of materials and are available in many different shapes and configurations. Culvert selection factors include roadway profiles, channel characteristics, flood damage evaluations, construction and maintenance costs, and estimates of service life.

824.2 Shape and Cross Section

(1) Numerous cross-sectional shapes are available. The most commonly used shapes include circular, box (rectangular), elliptical, pipe-arch, and arch. The shape selection is based on the cost of construction, the limitation on upstream water surface elevation, roadway embankment height, and hydraulic performance.

(2) Multiple Barrels. In general, the spacing of pipes in a multiple installation, measured between outside surfaces, should be at least half the nominal diameter with a minimum of 2 feet.

See Standard Plan D89 for multiple pipe headwall details.

Additional clearance between pipes is required to accommodate flared end sections. See Standard Plans, D94A & B for width of flared end sections.

Topic 825 - Hydraulic Design of Culverts

825.1 Introduction

After the design discharge, (Q), has been estimated, the conveyance of this water must be investigated. This aspect is referred to as hydraulic design.

The highway culvert is a special type of hydraulic structure. An exact theoretical analysis of culvert flow is extremely complex because the flow is usually non-uniform with regions of both gradually varying and rapidly varying flow. Hydraulic jumps often form inside or downstream of the culvert barrel. As the flow rate and tailwater elevations change, the flow type within the barrel changes. An exact hydraulic analysis therefore involves backwater and drawdown calculations, energy and momentum balance, and application of the results of hydraulic studies.

An extensive hydraulic analysis is usually impractical and not warranted for the design of most highway culverts. The culvert design procedures presented herein and in the referenced publications are accurate, in terms of head, to within plus or minus 10 percent.

825.2 Culvert Flow

The types of flow and control used in the design of highway culverts are:

- Inlet Control - Most culverts operate under inlet control which occurs when the culvert barrel is capable of carrying more flow than the inlet will accept. Supercritical flow is usually encountered within the culvert barrel. When the outlet is submerged under inlet control, a hydraulic jump will occur within the barrel.
- Outlet Control - Outlet control occurs when the culvert barrel is not capable of conveying as much flow as the inlet will accept. Culverts under outlet control generally function with submerged outlets and subcritical flow within the culvert barrel. However, it is possible for the culvert to function with an unsubmerged outlet under outlet control where flow

passes through critical depth in the vicinity of the outlet.

For each type of control, different factors and formulas are used to compute the hydraulic capacity of a culvert. Under inlet control, the cross sectional area of the culvert, inlet geometry, and elevation of headwater at entrance are of primary importance. Outlet control involves the additional consideration of the tailwater elevation of the outlet channel and the slope, roughness and length of the culvert barrel. A discussion of these two types of control with charts for selecting a culvert size for a given set of conditions is included in the FHWA Hydraulic Design Series No. 5, "Hydraulic Design of Highway Culverts."

825.3 Computer Programs

Numerous calculator and computer programs are available to aid in the design and analysis of highway culverts. The major advantages of these programs over the traditional hand calculation method are:

- Increased accuracy over charts and nomographs.
- Rapid comparison of alternative sizes and inlet configurations.

Familiarity with culvert hydraulics and traditional methods of solution is necessary to provide a solid basis for designers to take advantage of the speed, accuracy, and increased capabilities of hydraulic design computer programs.

The hydraulic design calculator and computer programs available from the FHWA are more fully described in HDS No. 5, "Hydraulic Design of Highway Culverts."

The HY8 culvert hydraulics program provides interactive culvert analysis. Given all of the appropriate data, the program will compute the culvert hydraulics for circular, rectangular, elliptical, arch, and user-defined culverts.

The logic of HY8 involves calculating the inlet and outlet control headwater elevations for the given flow. The elevations are then compared and the larger of the two is used as the controlling elevation. In cases where the headwater elevation is greater then the top elevation of the roadway embankment, an overtopping analysis is done in which flow is balanced between the culvert discharge and the surcharge over the roadway. In the cases where the culvert is not full for any part of its length, open channel computations are performed.

825.4 Coefficient of Roughness

Suggested Manning's n values for culvert design are given in Table 852.1.

Topic 826 - Entrance Design

826.1 Introduction

The size and shape of the entrance are among the factors that control the level of ponding at the entrance. Devices such as rounded or beveled lips and expanded entrances help maintain the velocity of approach, increase the culvert capacity, and may lower costs by permitting a smaller sized culvert to be used.

The inherent characteristics of common entrance treatments are discussed in Index 826.4. End treatment on large culverts is an important consideration. Selecting an appropriate end treatment for a specific type of culvert and location requires the application of sound engineering judgment.

The FHWA Hydraulic Design Series No. 5, "Hydraulic Design of Highway Culverts" combines culvert design information previously contained in HEC No. 5, No. 10, and No. 13. The hydraulic performance of various entrance types is described in HDS No. 5.

826.2 End Treatment Policy

The recommended end treatment for small culverts is the prefabricated flared end section. For safety, aesthetic, and economic reasons, flared end sections should be used at both entrance and outlet whenever feasible instead of headwalls.

End treatment, either flared end section or headwall, is required for circular culverts 60 inches or more in diameter and for pipe arches of equivalent size.

Plans for concrete arch and structural plate vehicular undercrossings.

- Where foundation material will not support footing pressures shown in the Highway Design Manual for structural plate pipe arches or corrugated metal pipe arches.
- Where a culvert will be subjected to unequal lateral pressures, such as at the toe of a fill or adjacent to a retaining wall.

Special designs usually require that a detailed foundation investigation be made.

(4) *Minimum Cover*. When feasible, culverts should be buried at least 1 foot. For construction purposes, a minimum cover of 6 inches greater than the thickness of the structural cross section is desirable for all types of pipe. The minimum thickness of cover for various type culverts under rigid or flexible pavements is given in Table 856.5.

829.3 Piping

Piping is a phenomenon caused by seepage along a culvert barrel which removes fill material, forming a hollow similar to a pipe. Fine soil particles are washed out freely along the hollow and the erosion inside the fill may ultimately cause failure of the culvert or the embankment.

The possibility of piping can be reduced by decreasing the velocity of the seepage flow. This can be reduced by providing for watertight joints. Therefore, if piping through joints could become a problem, consideration should be given to providing for watertight joints.

Piping may be anticipated along the entire length of the culvert when ponding above the culvert is expected for an extended length of time, such as when the highway fill is used as a detention dam or to form a reservoir. Headwalls, impervious materials at the upstream end of the culvert, and anti-seep or cutoff collars increase the length of the flow path, decrease the hydraulic gradient and the velocity of flow and thus decreases the probability of piping developing. Anti-seep collars usually consist of bulkhead type plate or blocks around the entire perimeter of the culvert. They may be of metal or concrete, and, if practical, should be keyed into impervious material.

Piping could occur where a culvert must be placed in a live stream, and the flow cannot be diverted. Under these conditions watertight joints should be specified.

829.4 Joints

The possibility of piping being caused by open joints in the culvert barrel may be reduced through special attention to the type of pipe joint specified. For a more complete discussion of pipe joint requirements see Index 854.1.

The two pipe joint types specified for culvert installations are identified as "standard" and "positive". The "standard" joint is adequate for ordinary installations and "positive" joints should be specified where there is a need to withstand soil movements or resist disjointing forces. Corrugated metal pipe coupling band details are shown on Standard Plan sheets D97A through D97G and concrete pipe joint details on sheet D97H.

If it is necessary for "standard" or "positive" joints to be watertight they must be specifically specified as such. Rubber "O" rings or other resilient joint material provides the watertight seal. Corrugated metal pipe joints identified as "downdrain" are watertight joint systems with a tensile strength specification for the coupler.

829.5 Anchorage

Refer to Index 834.4(5) for discussion on anchorage for overside drains.

Reinforced concrete pipe should be anchored and have positive joints specified if either of the following conditions is present:

(a) Where the pipe diameter is 60 inches or less, the pipe slope is 33 percent or greater, and the fill over the top of the pipe less than 1.5 times the outside diameter of the pipe measured perpendicular to the slope.

(b) Where the pipe diameter is greater than 60 inches and the pipe slope is 33 percent or greater, regardless of the fill over the top of the pipe.

Where the slopes have been determined by the geotechnical engineer to be potentially unstable, regardless of the slope of the pipe, as a minimum, the pipes shall have positive joints. Alternative pipes/anchorage systems shall be investigated when there is a potential for substantial movement of the soil.

Where anchorage is required, there should be a minimum of 18 inches cover measured perpendicular to the slope.

Typically buried flexible pipe with corrugations on the exterior surface will not require anchorage, however, a special detail will be required for plastic pipe without corrugations on the exterior surface.

829.6 Irregular Treatment

(1) *Junctions.* (Text Later)

(2) *Bends.* (Text Later)

829.7 Siphons and Sag Culverts

(1) *General Notes.* There are two kinds of conduits called siphons: the true siphon and the inverted siphon or sag culvert. The true siphon is a closed conduit, a portion of which lies above the hydraulic grade line. This results in less than atmospheric pressure in that portion. The sag culvert lies entirely below the hydraulic grade line; it operates under pressure without siphonic action.

Under the proper conditions, there are hydraulic and economic advantages to be obtained by using the siphon principle in culvert design.

(2) *Sag Culverts.* This type is most often used to carry an irrigation canal under a highway when the available headroom is insufficient for a normal culvert. The top of a sag culvert should be at least 4.5 feet below the finished grade where possible, to ensure against damage from heavy construction equipment. The culvert should be on a straight grade and sumps provided at each end to facilitate maintenance. Sag culverts should not be used:

(a) When the flow carries trash and debris in sufficient quantity to cause heavy deposits,

(b) For intermittent flows where the effects of standing water are objectionable, or

(c) When any other alternative is possible at reasonable cost.

(3) *Types of Conduit.* Following are two kinds of pipes used for siphons and sag culverts to prevent leakage:

(a) Reinforced Concrete Pipe - Reinforced concrete pipe with joint seals is generally satisfactory. For heads over 6 m, special consideration should be given to hydrostatic pressure.

(b) Corrugated Metal Pipe - corrugated metal pipe must be of the thickness and have the protective coatings required to provide the design service life. Field joints must be watertight. The following additional treatment is recommended.

- When the head is more than 10 feet and the flow is continuous or is intermittent and of long duration, pipe fabricated by riveting, spot welding or continuous helical lockseam should be soldered.

  Pipe fabricated by a continuous helical welded seam need not be soldered.

- If the head is 10 feet or less and the flow is intermittent and lasts only a few days, as in storm flows, unsoldered seams are permissible.

829.8 – Currently Not In Use

829.9 Dams

Typically, proposed construction which is capable of impounding water to the extent that it meets the legal definition of a dam must be approved by the Department of Water Resource (DWR), Division of Safety of Dams. The legal definition is described in Sections 6002 and 6003 of the State Water Code. Generally, any facility 25 feet or more in height or capable of impounding 50 acre-feet or more would be considered a dam. However, any facility 6 feet or less in height, regardless of capacity, or with a storage capacity of not more than 15 acre-feet, regardless of height, shall not be considered a dam. Additionally, Section 6004 of the State Water Code states "... and no road or highway fill or structure ... shall be considered a dam." Therefore, except for large retention or detention facilities there will rarely be the need for involvement by the DWR in approval of Caltrans designs.

Although most highway designs will be exempt from DWR approval, caution should always be exercised in the design of high fills that could impound large volumes of water. Even partial plugging of the cross drain could lead to high pressures on the upstream side of the fill, creating seepage through the fill and/or increased potential for piping.

The requirements for submitting information to the FHWA Division Office in Sacramento as described in Index 805.6 are not affected by the regulations mentioned above.

829.10 Reinforced Concrete Box Modifications

(1) *Extensions.* Where an existing box culvert is to be lengthened, it is essential to perform an on-site investigation to verify the structural integrity of the box. If signs of distress are present, the Division of Structures must be contacted prior to proceeding with the design.

(2) *Additional Loading.* When significant additional loading is proposed to be added to an existing reinforced concrete box culvert the Division of Structures must be contacted prior to proceeding with the design. Overlays of less than 6 inches in depth, or widenings that do not increase the per unit loading on the box are not considered to be significant. Designers should also check the extent that previous projects might have increased loading on box culverts, even if the current project is not adding a significant amount of loading.

834.3 Ditches and Gutters

(1) *Grade.* The flattest grade recommended for design is 0.25 percent for earth ditches and 0.12 percent for paved ditches.

(2) *Slope Ditches.* Slope ditches, sometimes called surface, brow, interception, or slope protection ditches, should be provided at the tops of cuts where it is necessary to intercept drainage from natural slopes inclined toward the highway.

When the grade of a slope ditch is steep enough that erosion would occur, the ditch should be paved. Refer to Table 862.2 for permissible velocities for unlined channels in various types of soil. When the ditch grade exceeds a 4:1 slope, a downdrain is advisable. Slope ditches may not be necessary where side slopes in favorable soils are flatter than 2:1 or where positive erosion control measures are to be instituted during construction.

(3) *Side Gutters.* These are triangular gutters adjoining the shoulder as shown in Figures 307.2 and 307.5. The main purpose of the 3 feet wide side gutter is to prevent runoff from the cut slopes on the high side of superelevation from flowing across the roadbeds. The use of side gutters in tangent alignment should be avoided where possible. Local drainage conditions, such as in snow areas, may require their use on either tangent or curved alignment in cut sections. In snow areas it may be necessary to increase the width of side gutters from 3 feet to 6 feet. The slope from the edge of the shoulder to the bottom of the gutter should be no steeper than 6:1. The structural section for paved side gutters should be adequate to support maintenance equipment loads.

(4) *Dikes.* Dikes placed adjoining the shoulder, as shown in Figures 307.2, 307.4, and 307.5, provide a paved triangular gutter within the shoulder area. For conditions governing their use, see Index 303.3.

(5) *Chart Solutions.* Charts for solutions to triangular channel flow problems are contained in FHWA Hydraulic Engineering Circular No. 22, "Urban Drainage Design Manual".

834.4 Overside Drains

The purpose of overside drains, sometimes called slope drains, is to protect slopes against erosion. They convey down the slope drainage which is collected from the roadbed, the tops of cuts, or from benches in cut or fill slopes. They may be pipes, flumes or paved spillways.

(1) *Spacing and Location.* The spacing and location of overside drains depend on the configuration of the ground, the highway profile, the quantity of flow and the limitations on flooding stated in Table 831.3. When possible, overside drains should be positioned at the lower end of cut sections. Diversion from one watershed to another should be avoided. If diversion becomes necessary, care should be used in the manner in which this diverted water is disposed.

Overside drains which would be conspicuous or placed in landscaped areas should be concealed by burial or other means.

(2) *Type and Requirement.* Following are details of various types of overside drains and requirements for their use:

(a) Pipe Downdrains. Metal and plastic pipes are adaptable to any slope. They should be used where side slopes are 4:1 or steeper. Long pipe downdrains should be anchored.

The minimum pipe diameter is 8 inches but large flows, debris, or long pipe installations may dictate a larger diameter.

Watertight joints are necessary to prevent leakage which causes slope erosion. Economy in long, high capacity downdrains is achieved by using a pipe taper in the initial reach. Pipe tapers should insure improved flow characteristics and permit use of a smaller diameter pipe below the taper. See Standard Plan D87-A for details.

(b) Flume Downdrains. These are rectangular corrugated metal flumes with a tapered entrance. See the Standard Plan D87-D for details. They are best adapted to slopes that are 2:1 or flatter but if used on 1.5:1 slopes, lengths over 60 feet are not recommended. Abrupt changes in alignment or grade should be avoided. Flume downdrains should be depressed so that the top of the flume is flush with the fill slope.

(c) Paved Spillways. Permanent paved spillways should only be used when the side slopes are flatter than 4:1. On steeper slopes a more positive type of overside drain such as a pipe downdrain should be used.

Temporary paved spillways are effective in preserving raw fill slopes that are 6:1 or flatter in friable soils during the period when protective growth is being established. Paved spillways should be spaced so that a dike 2 inches high placed at the outer edge of the paved shoulder will effectively confine drainage between spillways. When it is necessary to place a spillway on curved alignment, attention must be given to possible overtopping at the bends. See Index 866.2(3) for discussion of superelevation of the water surface.

(3) Entrance Standards. Entrance tapers for pipes and flume downdrains are detailed on the Standard Plans. Pipe entrance tapers should be depressed at least 6 inches.

The local depressions called "paved gutter flares" on the Standard Plans are to be used at all entrance tapers. See Standard Plans D87-A and D87-D for details and Index 837.5 for further discussion on local depressions.

In areas where local depressions would decrease safety the use of flush grate inlets or short sections of slotted drain for entrance structures may be necessary.

(4) Outlet Treatment. Where excessive erosion at an overside drain outlet is anticipated, a simple energy dissipator should be employed. Preference should be given to inexpensive expedients such as an apron of broken concrete or rock, a short section of pipe placed with its axis vertical with the lowermost 6 inches filled with coarse gravel or rock, or a horizontal tee section which is usually adequate for downdrain discharges.

(5) Anchorage. For slopes flatter than 3:1 overside drains do not need to be anchored. For slopes 3:1 or steeper overside drains should be anchored with 6 foot pipe stakes as shown on the Standard Plans to prevent undue strain on the entrance taper or pipe ends. For drains over 150 feet long, and where the slope is steeper than 2:1, cable anchorage should be considered as shown on the Standard Plans. Where the cable would be buried and in contact with soil, a solid galvanized rod should be used the buried portion and a cable, attached to the rod, used for the exposed portion. Beyond the buried portion, a slip joint must be provided when the installation exceeds 60 feet in length. Regard-less of pipe length or steepness of slope, where there is a potential for hillside movement cable anchorage should be considered.

When cable anchorage is used as shown on the Standard Plans, the maximum allowable downdrain lengths shall be 200 feet for a slope of 1.5:1 and 250 feet for a slope of 2:1. For pipe diameters greater than 24 inches, or downdrains to be placed on slopes steeper than 1.5:1, special designs are required. Where there is an abrupt change in direction of flow, such as at the elbow or a tee section downstream of the end of the cable anchorage system, specially designed thrust blocks should be considered.

(6) Drainage on Benches. Drainage from benches in cut and fill slopes should be removed at intervals ranging from 300 feet to 500 feet.

(7) Selection of Types. Pipe and flume downdrains may consist of either corrugated steel, corrugated aluminum, or any other approved material that meets the minimum design service life required under Chapter 850. Refer to Index 855.2 for additional discussion on limitations of abrasive resistance of aluminum pipe culverts.

(b) Paved Gutter Flares. The local depression which adjoins the outer edge of shoulder at the entrance to overside downdrains and spillways is labeled "paved gutter flare" on Standard Plans D87-A and D87-D. The flow line approaching the inlet is depressed to increase capacity and minimize water spread on the roadbed. Within a flare length of 10 feet the gutter flow line is depressed a minimum of 6 inches at the inlet. Recommended flare lengths for various gutter flow line depression depths are given on the Standard Plans. When conditions warrant, these flare lengths may be exceeded.

Traffic safety should not be compromised for hydraulic efficiency. Any change in the shape of the paved gutter flare that will result in a depression within the shoulder area should not be made. The Type 2 entrance taper and paved gutter flare is intended for use on divided highways where gutter grades exceed 2 percent and flow is in the opposite direction of traffic.

(c) Roadside Gutter and Ditch Locations. Regardless of type of intake, the opening of a drop inlet in a roadside gutter or ditch should be depressed from 4 inches to 6 inches below the flow line of the waterway with 10 feet of paved transition upstream.

(d) Curb and Gutter Depressions. This type of depression is carefully proportioned in length, width, depth, and shape. To best preserve the design shape, construction normally is of concrete. Further requirements for curb and gutter depressions are:

- Length - As shown on Standard Plan D78.
- Width - Normally 4 feet, but for wide flows or a series of closely spaced inlets, 6 feet is authorized.
- Depth - Where traffic considerations govern, the depth commonly used is 0.1 foot. Use the maximum of 0.25 foot wherever feasible at locations where the resulting curb height would not be objectionable.

(e) Type of Pavement. Local depressions outside the roadbed are usually surfaced with asphalt concrete 0.15 foot thick.

(3) General Notes on Design. Except for traffic safety reasons, a local depression is to be provided at every inlet even though the waterway is unpaved. Where the size of intake opening is a question, a depression of maximum depth should be considered before deciding on a larger opening. For traffic reasons, the gutter depression should be omitted in driveways and median curb and gutter installations.

It is permissible to omit gutter depressions at sump inlets where the width of flow does not exceed design water spread.

Topic 838 - Storm Drains

838.1 General

The total drainage system which conveys runoff from roadway areas to a positive outlet including gutters, ditches, inlet structures, and pipe is generally referred to as a storm drain system. In urban areas a highway storm drain often augments an existing or proposed local drainage plan and should be compatible with the local storm drain system.

This section covers the hydraulic design of the pipe or enclosed conduit portion of a storm drain system.

838.2 Design Criteria

To adequately estimate design storm discharges for a storm drain system in urban areas involving street flooding it may be necessary to route flows by using hydrograph methods. Hydrographs are discussed under Index 816.5 and further information on hydrograph methods may be found in Chapters 6 and 7 of HDS No.2, Highway Hydrology.

838.3 Hydraulic Design

Closed conduits should be designed for the full flow condition. They may be allowed to operate under pressure, provided the hydraulic gradient is 0.75 foot or more below the intake lip of any inlet that may be affected. The energy gradient should not rise above the lip of the intake. Allowances should be made for energy losses at bends, junctions and transitions.

To determine the lowest outlet elevation for drainage systems which discharge into leveed channels or bodies of water affected by tides, consideration should be given to the possibilities of backwater. The effect of storm surges (e.g., winds and floods) should be considered in addition to the predicted tide elevation.

Normally, special studies will be required to determine the minimum discharge elevation consistent with the design discharge of the facility.

838.4 Standards

(1) *Location and Alignment.* Longitudinal storm drains are not to be placed under the traveled way of highways. Depending upon local agency criteria, storm drains under the traveled way of other streets and roads may be acceptable. A manhole or specially designed junction structure is usually provided at changes in direction or grade and at locations where two or more storm drains are joined. Refer to Index 838.5 for further discussion on manholes and junction structures.

(2) *Pipe Diameter.* The minimum pipe diameter to be used is given in Table 838.4.

Table 838.4

Minimum Pipe Diameter for Storm Drain Systems

Type of Drain	Minimum Diameter (in)
Trunk Drain	18
Trunk Laterals	15[(1)]
Inlet Laterals	15[(1)]

(1) 18 minimum if wholly or partly under the roadbed.

(3) *Slope.* The minimum longitudinal slope should be such that when flowing half full, a self cleaning velocity of 3 feet per second is attained.

(4) *Physical Properties.* In general, the considerations which govern the selection of culvert type apply to storm drain conduits. Alternative types of materials, overfill tables and other physical factors to be considered in selecting storm drain conduit are discussed under Chapter 850.

Specific subjects for special consideration are:

- Bedding and Backfill. Bedding and backfill consideration are discussed under Index 829.2. Maximum height of cover tables are included in Chapter 850 and minimum thickness of cover is given in Table 856.5.
- Roughness Factor. The roughness factor, Manning's n value, generally assumes greater importance for storm drain design than it does for culverts. Suggested Manning's n values for various types of pipe materials are given in Table 852.1.

(5) *Storage.* In developing the most economical installation, the designer should not overlook economies obtainable through the use of pipeline storage and, within allowable limits, the ponding of water in gutters, medians and interchange areas. Inlet capacity and spacing largely control surface storage in gutters and medians; inlet capacity governs in sump areas.

(6) *Floating Trash.* Except at pumping installations, every effort should be made to carry all floating trash through the storm drain system. Curb and wall opening inlets are well suited for this purpose. In special cases where it is necessary to exclude trash, as in pumping installations, a standard trash rack must be provided across all curb and wall openings of tributary inlets. See the Standard Plans for details.

centerline. Conditions may be such that trench alignment on a skew or with tee, wye, or herringbone configurations are a better design.

Lining the trench with filter fabric is recommended. The usual 3 feet or more thickness of permeable material may be reduced and a less expensive gradation may be specified if a filter fabric is used. Assistance in selecting filter fabric and permeable material specifications should be requested from Geotechnical Services.

- *Drainage Galleries*. Drainage galleries consist of a row or rows of closely spaced wells 36 inches to 48 inches in diameter bored with power augers to the depth required to intercept the aquifer. They are a variation of the stabilization trench principle and may afford a more cost effective solution under certain conditions.

  Drainage galleries are a viable option where the depth of the aquifer exceeds the economical or practical limits for open trench excavation. Because of potential cave-ins or slides, open trench excavation may not be practical.

  The bottom of the bored wells should be interconnected and a suitable collector and outlet system must be provided. The wells may be interconnected by belling out at the bottoms, tunneling between wells, drilled-in-place outlets, or horizontal drains.

  The wells are backfilled with permeable material. The Geotechnical Design Report should contain well spacing and depth recommendations. Assistance in selecting permeable material and other specifications pertinent to drainage galleries should be requested from Geotechnical Services.

Topic 842 - Pipe Underdrains

842.1 General

As stated under Index 841.5, the standard underdrain treatment is the perforated pipe underdrain. Pipe underdrain systems consist of a 6-inch or 8-inch diameter perforated pipe placed near the bottom of a narrow trench. The trench is usually lined with filter fabric prior to placement of the perforated pipe and permeable material backfill.

Two standard cross sections for pipe underdrains are shown on Standard Plan D102. The one with the permeable material carried to the top of the grading plane is used under paved areas. The other, with a topping of earth backfill over the permeable material, is used under unpaved areas.

842.2 Single Installations

A single pipe underdrain is commonly used in these cases:

- Along the toe of a cut slope to intercept seepage when slope stability is not a problem.
- Along the toe of a fill on the side from which groundwater originates.
- Across the roadway at the downhill end of a cut.

842.3 Multiple Installations

Multiple underdrain installations may be used in a herringbone or other effective pattern in situations such as the following:

- Under the roadway structural section when a permeable blanket is required.
- To stabilize fill foundation areas.

Refer to Table 842.4 for a guide to selecting depth and spacing of multiple pipe underdrain installations.

842.4 Design Criteria

- *Size and Length*. For pipe underdrains of 500 feet or less in length, the standard perforated pipe size is 6 inches in diameter. As a rule, the 6-inch diameter is adequate for collectors and laterals in most soils. For lengths exceeding 500 feet, the minimum diameter of pipe is 8 inches.
- *Surface Runoff*. Surface drainage should be prevented from discharging into underdrain systems.

- *Outlets*. Underdrain outlets should be provided at intervals of not more than 1,000 feet.

  Underdrain systems may be designed to discharge directly into a storm drain or culvert as long as the underdrain outlet is not subjected to hydrostatic pressures that could cause backflow damage.

- *Cleanouts*. Terminal and intermediate risers may be placed for the convenience of the maintenance forces cleaning the system. When practical, a terminal riser should be placed at the upper end of an underdrain. Intermediate cleanout risers may be placed at intervals of 500 feet and at sharp angle points greater than 10 degrees.

  The diameter of risers should be the same as the pipe underdrain. Details of underdrain risers are shown on Standard Plan D102.

- *Grade*. If possible, pipe underdrains should be placed on grades steeper than 0.5 percent. Minimum grades of 0.2 percent for laterals and 0.25 percent for mains are acceptable.

- *Depth and Spacing*. The depth of the underdrain depends on the permeability of the soil, the elevation of the water table, and the amount of drawdown needed to ensure stability. Whenever practicable, an underdrain pipe should be set in the impervious zone below the aquifer. Additionally, consideration should be given to the depth and proximity of storm drains. Typically, the underdrain should be placed at a depth sufficient to keep the storm drain above the groundwater table.

  Table 842.4 gives suggested depths and spacing of underdrains according to soil types. It is only a guide and should not be considered a substitute for field observations or local experience.

842.5 Types of Underdrain Pipe

The aim of any underdrain installation is long term effectiveness. This aim is associated with filtering ability, durability, strength, and cost of conduit, mainly in that order. In choosing between pipes of different types, the key considerations are filtering ability and durability. Pipe cost assumes secondary importance because it is a minor part of the underdrain investment.

Pipes for underdrains are perforated and may be made of steel, aluminum, polyvinyl chloride (PVC) or polyethylene, all with corrugated profiles, or smooth wall PVC. All of the listed types are acceptable for either shallow or deep burial situations. Where plastic pipe underdrains are proposed and burial depths would exceed 30 feet, the Underground Structures Unit in the Division of Engineering Services should be contacted for approval.

842.6 Design Service Life

Refer to Chapter 850 for further discussion and criteria relative to design service life of pipe materials used in underdrain installations.

Experience with underdrains has shown that they are not subject to corrosion in an environment that lacks an adequate supply of air and oxygen entrained in the water. Subsurface waters that may be inclined to be corrosive chemically do not tend to become so as long as they are not exposed to oxygen. However, subsurface water may become corrosive after it has surfaced and been exposed to oxygen. Furthermore, there is evidence that indicates there is little oxygen available in long lengths of the small diameter pipe normally used in a subsurface drainage system.

Although tests may indicate that corrosive salts are present in the soil solution, corrosion will not take place without the presence of oxygen. Therefore, when it is anticipated that the underdrain will be placed to intercept groundwater under the above conditions, it will not be necessary to allow for metal pipe corrosion.

When the above conditions do not prevail, the design service life of metal pipe is determined from pH and resistivity tests covered in California Test 643. This information is shown in the Geotechnical Design Report. The design service life of steel pipe may be increased by a bituminous coating as indicated in Table 855.2C.

The guide values contained in the tables mentioned above may be modified where field observation of existing installations dictates.

842.7 Pipe Selection

In cases where more than one material meets the foregoing requirements, alternatives should be specified on the basis of optional selection by the contractor. The selection of a single type of underdrain may be appropriate due to other related factors. This selection should be supported by complete analysis of factors and documentation placed on file in the District.

Table 842.4

Suggested Depth and Spacing of Pipe Underdrains for Various Soil Types

	Soil Composition			**Drain Spacing (ft)**			
Soil Class	Percent Sand	Percent Silt	Percent Clay	3 feet Deep	4 feet Deep	5 feet Deep	6 feet Deep
Clean Sand	80-100	0-20	0-20	110 - 150	150 - 200	- -	- -
Sandy Loam	50-80	0-50	0-20	50 - 100	100 - 150	- -	- -
Loam	30-50	30-50	0-20	30 - 60	40 - 80	50 - 100	60 - 120
Clay Loam	20-50	20-50	20-30	20 - 40	25 - 50	30 - 60	40 - 80
Sandy Clay	50-70	0-20	30-50	15 - 30	20 - 40	25 - 50	30 - 60
Silty Clay*	0-20	50-70	30-50	10 - 25	15 - 30	20 - 40	25 - 50
Clay*	0-50	0-50	30-100	15(max)	20(max)	25(max)	40(max)

* Drainage blankets or stabilization trenches should be considered.

CHAPTER 850
PHYSICAL STANDARDS

Topic 851 - General

Index 851.1 - Introduction

This chapter deals with the selection of drainage facility material type and sizes including pipes, pipe liners, pipe linings, drainage inlets and trench drains.

851.2 Selection of Material and Type

The choice of drainage facility material type and size is based on the following factors:

(1) *Physical and Structural Factors.* Of the many physical and structural considerations, some of the most important are:

(a) Durability.

(b) Headroom.

(c) Earth Loads.

(d) Bedding Conditions.

(e) Conduit Rigidity.

(f) Impact.

(g) Leak Resistance.

(2) *Hydraulic Factors.* Hydraulic considerations involve:

(a) Design Discharge.

(b) Shape, slope and cross sectional area of channel.

(c) Velocity of approach.

(d) Outlet velocity.

(e) Total available head.

(f) Bedload.

(g) Inlet and outlet conditions.

(h) Slope.

(i) Smoothness of conduit.

(j) Length.

Suggested values for Manning's Roughness coefficient (n) for design purposes are given in Table 852.1 for each type of conduit. See Index 864.3 for use of Manning's formula.

Topic 852 - Pipe Materials

852.1 Reinforced Concrete Pipe (RCP)

(1) *Durability.* RCP is generally precast prior to delivery to the project site. The durability of reinforced concrete pipe can be affected by abrasive flows or acids, chlorides and sulfate in the soil and water. See Index 855.2 Abrasion, and Index 855.4 Protection of Concrete Pipe and Drainage Structures from Acids, Chlorides and Sulfates.

The following measures increase the durability of reinforced concrete culverts:

(a) Cover Over Reinforcing Steel. Additional cover over the reinforcing steel should be specified where abrasion is likely to be severe as to appreciably shorten the design service life of a concrete culvert. This extra cover is also warranted under exposure to corrosive environments, see Index 855.4 Protection of Concrete Pipe and Drainage Structures from Acids, Chlorides and Sulfates. Extra cover over the reinforcing steel does not necessarily require extra wall thickness, as it may be possible to provide the additional cover and still obtain the specified D-load with standard wall thicknesses.

(b) Increase cement content.

(c) Reduce water content.

(d) Invert paving/plating.

(2) *Strength Requirements.*

(a) Design Standards. The strength of reinforced concrete pipe is determined by the load to produce a 0.01 inch crack under the “3-edge bearing test” called for in AASHTO Designations M 170, M 207M/M 207, and M 206M/M 206 for circular reinforced pipe, oval shaped reinforced pipe, and reinforced concrete pipe arches, respectively.

Table 852.1

Manning "n" Value for Alternative Pipe Materials(1)

Type of Conduit		Recommended Design Value	"n" Value Range
Corrugated Metal Pipe (2)			
(Annular and Helical) (3)			
2⅔" x ½"	corrugation	0.025	0.022 - 0.027
3" x 1"	"	0.028	0.027 - 0.028
5" x 1"	"	0.026	0.025 - 0.026
6" x 2"	"	0.035	0.033 - 0.035
9" x 2½"	"	0.035	0.033 - 0.037
Concrete Pipe			
Pre-cast		0.012	0.011 - 0.017
Cast-in-place		0.013	0.012 - 0.017
Concrete Box		0.013	0.012 - 0.018
Plastic Pipe (HDPE and PVC)			
Smooth Interior		0.012	0.010 - 0.013
Corrugated Interior		0.022	0.020 - 0.025
Spiral Rib Metal Pipe			
¾" (W) x 1" (D) @ 11½" o/c		0.013	0.011 - 0.015
¾" (W) x ¾" (D) @ 7½" o/c		0.013	0.012 - 0.015
¾" (W) x 1" (D) @ 8½" o/c		0.013	0.012 - 0.015
Composite Steel Spiral Rib Pipe		0.012	0.011 - 0.015
Steel Pipe, Ungalvanized		0.015	--
Cast Iron Pipe		0.015	--
Clay Sewer Pipe		0.013	--
Polymer Concrete Grated Line Drain		0.011	0.010 - 0.013

Notes:

(1) Tabulated n-values apply to circular pipes flowing full except for the grated line drain. See Note 5.

(2) For lined corrugated metal pipe, a composite roughness coefficient may be computed using the procedures outlined in the HDS No. 5, Hydraulic Design of Highway Culverts.

(3) Lower n-values may be possible for helical pipe under specific flow conditions (refer to FHWA's publication Hydraulic Flow Resistance Factors for Corrugated Metal Conduits), but in general, it is recommended that the tabulated n-value be used for both annular and helical corrugated pipes.

(4) For culverts operating under inlet control, barrel roughness does not impact the headwater. For culverts operating under outlet control barrel roughness is a significant factor. See Index 825.2 Culvert Flow.

(5) Grated Line Drain details are shown in Standard Plan D98C and described under Index 837.2(6) Grated Line Drains. This type of inlet can be used as an alternative at the locations described under Index 837.2(5) Slotted Drains. The carrying capacity is less than 18-inch slotted (pipe) drains.

(b) Height of Fill. See Topic 856.

(3) *Shapes.* Reinforced concrete culverts are available in circular and oval shapes. Reinforced Concrete Pipe Arch (RCPA) shapes have been discontinued by West Coast manufacturers.

In general, the circular shaped is the most economical for the same cross-sectional area. Oval shapes are appropriate for areas with limited head or overfill or where these shapes are more appropriate for site conditions. A convenient reference of commercially available products and shapes is the AASHTO publication, "A Guide to Standardized Highway Drainage Products".

(4) *Non-Reinforced Concrete Pipe Option.* Non-reinforced concrete pipe may be substituted at the contractor's option for reinforced concrete pipe for all sizes 36 inches in diameter and smaller as long as it conforms to Section 65 of the Standard Specifications. Non-Reinforced concrete pipe is not affected by chlorides or stray currents and may be used in lieu of RCP in these environments without coating or the need to provide extra cover over reinforcement.

(5) *Direct Design Method - RCP.* (Contact DES - Structures Design)

852.2 Cast-in-Place Non-reinforced Concrete Pipe

(1) *Design Criteria.*

(a) Use of cast-in-place non-reinforced concrete pipe should not be considered when an unstable trench condition occurs; for example, it should not be installed under the following conditions:

- Sandy and cohesionless soil.
- Shallow location in expansive soil where the volume change would crack pipe.
- Areas where ground is subject to freezing to considerable depths for lengthy periods.
- Marshy, tidal areas and other areas of subsidence or differential settlement.
- Locations near geologic faults or where potential for liquefaction exists.

(b) Cover between top of pipe and ground surface should be at least 2.5 feet, or 2 feet below the grading plane. In expansive soils, cover should be a minimum of 3 feet. Some special treatment may be needed in expansive soil, depending on moisture content.

(c) Cast-in-place non-reinforced concrete pipe may be used only if static head is intermittent and less than 12 feet above center of pipe, and some leakage is acceptable.

(d) Installation under any State Highway Roadbed is only permissible with FHWA and/or headquarters and DES - Structures Design approval. Installations outside the roadbed are permissible, but the possibility of future widenings should be considered prior to finalizing the culvert location.

(e) See Table 855.4A for a guide to cementitious material restrictions and water content restrictions to be used with various ranges of sulfated concentrations in the soil and water. See Table 855.4A for limitations of use due to soil and water acidity. Also, Index 855.2 provides additional guidance for abrasion and invert protection. Maintenance-free service life, with respect to corrosion, abrasion and/or durability, is defined as the number of years from installation until the deterioration reaches the point of perforation or major cracking with soil loss at any point on the culvert.

(2) *Height of Fill.* See Topic 856.

852.3 Concrete Box and Arch Culverts

(1) *Box Culverts.* Single and multiple span reinforced concrete box culverts are completely detailed in the Standard Plans. For cast-in-place construction, strength classifications are shown for 10 feet and 20 feet overfills. Standard Detail Sheets are available for precast reinforced concrete box culverts. They may be obtained electronically, from the District Hydraulics Engineer or by contacting DES - Structures

Design. Precast reinforced concrete box culverts require a minimum of 1 foot of overfill and are not to exceed 12 feet in span length. Special details are necessary if precast boxes are proposed as extensions for existing box culverts. Where the use of precast box culverts is applicable, the project plans should include them as an alternative to cast-in-place construction. Because the standard measurement and payment clauses for precast RCB's differ from cast-in-place construction, precast units must be identified as an alternative on the standard detail sheets and the special provision must be appropriately modified.

The standard detail sheets for precast boxes show details which require them to be layed out with joints perpendicular to the centerline of the box. This is a consideration for the design engineer in situations which require stage construction and when the culvert is to be aligned on a high skew. This situation will require either a longer culvert than otherwise may have been needed, or a special design allowing for skewed joints. Prior to selecting the latter option DES - Structures Design should be consulted.

(2) *Concrete Arch Culverts.* Technical questions regarding concrete arch culverts should be directed to the Underground Structures Branch of DES - Structures Design.

(3) *Three-Sided Concrete Box Culverts* Design details for cast-in-place (CIP) construction three-sided bottomless concrete box culverts in 2-foot span increments from 12 feet to < 20 feet, inclusive, with strength classifications shown for 10 feet and 20 feet overfills are available upon request from DES - Structures Design. CIP Bottomless Culvert XS-sheets 17-050-1e, 2e, 3e, and 4e may be obtained electronically. Precast three-sided box culverts are an acceptable alternative to CIP designs, where contractors may submit such designs for approval. Both precast and CIP designs must be placed on a foundation designed specifically for the project site.

(4) *Corrosion, Abrasion, and Invert Protection.* Refer to Index 854.2 Abrasion, and Index 854.4 Protection of Concrete Pipe and Drainage Structures from Acids, Chlorides and Sulfates for corrosion, abrasion and invert protection of concrete box and arch culverts.

852.4 Corrugated Steel Pipe, Steel Spiral Rib Pipe and Pipe Arches

Corrugated steel pipe, steel spiral rib pipe and pipe arches are available in the diameters and arch shapes as indicated on the maximum height of cover tables. For larger diameters, arch spans or special shapes, see Index 852.6. Corrugated steel pipe and pipe arches are available in various corrugation profiles with helical and annular corrugations. Corrugated steel spiral rib pipe is available in several helical corrugation patterns.

(1) *Hydraulics.* Annular and helical corrugated steel pipe configurations are applicable in the situations where velocity reduction is important or if a culvert is being designed with an inlet control condition. Spiral rib pipe, on the other hand, may be more appropriate for use in stormdrain situations or if a culvert is being designed with an outlet control condition. Spiral rib pipe has a lower roughness coefficient (Manning's "n") than other corrugated metal pipe profiles.

(2) *Durability.* The anticipated maintenance-free service life of corrugated steel pipe, steel spiral rib pipe and pipe arch installations is primarily a function of the corrosivity and abrasiveness of the environment into which the pipe is placed. Corrosion potential must be determined from the pH and minimum resistivity tests covered in California Test 643. Abrasive potential must be estimated from bed material that is present and anticipated flow velocities. Refer to Index 855.1 for a discussion of maintenance-free service life and Index 855.2 Abrasion, and Index 855.3 Corrosion.

The following measures are commonly used to prolong the maintenance-free service life of steel culverts:

(a) Galvanizing. Under most conditions plain galvanizing of steel pipe is all that is needed; however, the presence of corrosive or abrasive elements may require additional protection.

- Protective Coatings - The necessity for any coating should be determined considering hydraulic conditions, local experience, possible environmental impacts, and long-term economy. Approved protective coatings are bituminous asphalt, asphalt mastic and polymeric sheet, which can be applied to the inside and/or outside of the pipe; polymerized asphalt, which is hot-dipped to cover the bottom 90° of the inside and outside of the pipe; and polyethylene for composite steel spiral ribbed pipe which is a steel spiral ribbed pipe externally pre-coated with a polymeric sheet, and internally polyethylene lined. All of these protective coatings are typically shop-applied prior to delivery to the construction site. Polymeric sheet coating provides much improved corrosion resistance over bituminous coatings and can be considered to typically allow achievement of a 50-year maintenance-free service life without need to increase thickness of the steel pipe. To ensure that a damaged coating does not lead to premature catastrophic failure, the base steel thickness for pipes that are to be coated with a polymeric sheet must be able to provide a minimum 10-year service life prior to application of the polymeric material. In addition, a bituminous lining or bituminous paving can be applied over a bituminous coating primer on the inside of the pipe for extra corrosion or abrasion protection (see Standard Specification 66-1.03, paragraphs 4 and 5).

Citing Section 5650 of the Fish and Game Code, the Department of Fish and Game (DFG) may restrict the use of bituminous coatings on the interior of pipes if they are to be placed in streams that flow continuously or for an extended period (more than 1 to 2 days) after a rainfall event. Their concern is that abraded particles of asphalt could enter the stream and degrade the fish habitat. Where abrasion is unlikely, DFG concerns should be minimal. DFG has indicated that they have no concerns regarding interior application of polymerized asphalt or polymeric sheet coatings, even under abrasive conditions.

Where the materials report indicates that soil side corrosion is expected, a bituminous asphalt coating which is hot-dipped to cover the entire inside and outside of the pipe or an exterior application of polymeric sheet, as provided in the Standard Specifications, combined with galvanizing of steel, is usually effective in forestalling accelerated corrosion on the backfill side of the pipe. Where soil side corrosion is the only, or primary, factor leading to deterioration, the bituminous asphalt protectoin layer described above is typically expected to add up to 25 years of service life to an uncoated (i.e., plain galvanized) pipe. A polymeric sheet coating is typically expected to provide up to 50-years of service life to an uncoated pipe. For locations where water side corrosion and/or abrasion is of concern, protective coatings, or protective coatings with pavings, or protective coatings with linings, in combination with galvanizing will add to the culvert service life to a variable degree, depending upon site conditions and type of coating selected. Refer to Index 855.2 Abrasion, and Index 855.3 Corrosion. If hydraulic conditions at the culvert site require a lining on the inside of the pipe or a coating different than that indicated in the Standard Specifications, then the different requirements must be described in the Special Provisions.

- Extra Metal Thickness. Added service life can be achieved by adding metal thickness. However, this should only be considered after protective coatings and pavings have been considered. Since 0.052 inch thick steel culverts is the minimum steel pipe Caltrans allows, it must be limited to locations that are nonabrasive.

See Table 855.2C for estimating the added service life that can be achieved by coatings and invert paving of steel pipes based upon abrasion resistance characteristics.

(b) Aluminized Steel (Type 2). Evaluations of aluminized steel (type 2) pipe in place for over 40 years have provided data that substantiate a design service life with respect to corrosion resistance equivalent to aluminum pipe. Therefore, for pH values between 5.5 and 8.5, and minimum resistivity values in excess of 1500 ohm-cm, 0.064 inch aluminized steel (type 2) is considered to provide a 50 year design service life. Where abrasion is of concern, aluminized steel (type 2) is considered to be roughly equivalent to galvanized steel. Bituminous coatings are not recommended for corrosion protection, but may be used in accordance with Table 855.2C for abrasion resistance. For pH ranges outside the 5.5 and 8.5 limits or minimum resistivity values below 1500 ohm-cm, aluminized steel (type 2) should not be used. In no case should the thickness of aluminized steel (type 2) be less than the minimum structural requirements for a given diameter of galvanized steel. Refer to Index 855.2 Abrasion, and Index 855.3 Corrosion.

The AltPipe Computer Program is also available to help designers estimate service life for various corrosive/abrasive conditions. See http://dap1.dot.ca.gov/design/altpipe/

(3) *Strength Requirements.* The strength requirements for corrugated steel pipes and pipe arches, fabricated under acceptable methods contained in the Standard Specifications, are given in Tables 856.3A, B, C, & D. For steel spiral rib pipe see Tables 856.3E, F & G.

(a) Design Standards.

- Corrugation Profiles - Corrugated steel pipe and pipe arches are available in 2⅔" x ½", 3" x 1", and 1" x 1" profiles with helical corrugations, and 2⅔" x ½" profiles with annular corrugations. Corrugated steel spiral rib pipe is available in a ¾" x ¾" x 7½" or ¾" x 1" x 11½" helical corrugation pattern. For systems requiring large diameter and/or deeper fill capacity a ¾" x 1" x 8½" helical corrugation pattern is available. Composite steel spiral rib pipe is available in a ¾" x ¾" x 7½" helical ribbed profile.
- Metal Thickness - Corrugated steel pipe and pipe arches are available in the thickness as indicated on Tables 856.3A, B, C & D. Corrugated steel spiral rib pipe is available in the thickness as indicated on Tables 856.3E, F & G. Where a maximum overfill is not listed on these tables, the pipe or arch size is not normally available in that thickness. Corrugated steel spiral rib pipe is available in the thickness as indicated on Tables 856.3E, F & G. Composite steel spiral rib pipe is available in the thickness as indicated on Table 856.3G.
- Height of Fill - The allowable overfill heights for corrugated steel and corrugated steel spiral rib pipe and pipe arches for the various diameters or arch sizes and metal thickness are shown on Tables 856.3A, B, C, & D. For corrugated steel spiral rib pipe, overfill heights are shown on Tables 856.3E, F & G. Table 856.3G gives the allowable overfill height for composite steel spiral rib pipe.

(4) *Shapes.* Corrugated steel pipe, steel spiral rib pipe and pipe arches are available in the diameters and arch shapes as indicated on the maximum height of cover tables. For larger diameters, arch spans or special shapes, see Index 852.6.

(5) *Invert Protection.* Refer to Index 855.2 Abrasion. Invert protection should be considered for corrugated steel culverts exposed to excessive wear from abrasive flows or corrosive water. Severe abrasion usually occurs when the flow velocity exceeds 12 feet per second to 15 feet per second and contains an abrasive bedload of sufficient

volume. When severe abrasion or corrosion is anticipated, special designs should be investigated and considered. Typical invert protection includes invert paving with portland cement concrete with wire mesh reinforcement, and invert lining with metal plate. Invert linings should cover the lower fourth of the periphery of circular pipes, and the lower third of pipe arches. Additional metal thickness will increase service life. Reducing the velocity within the culvert is an effective method of preventing severe abrasion. Index 853.6 provides additional guidance on invert paving with concrete.

(6) *Spiral Rib Steel.* Galvanized steel spiral rib pipe is fabricated using sheet steel and continuous helical lock seam fabrication as used for helical corrugated metal pipe. The manufacturing complies with Section 66, “Corrugated Metal Pipe,” of the Standard Specifications, except for profile and fabrication requirements. Spiral rib pipe is fabricated with either: three rectangular ribs spaced midway between seams with ribs 3/4" wide x 3/4" high at a maximum rib pitch of 7-1/2 inches, two rectangular ribs and one half-circle rib equally spaced between seams with ribs 3/4" wide x 1" high at a maximum rib pitch of 11-1/2 inches with the half-circle rib diameter spaced midway between the rectangular ribs, or two rectangular ribs equally spaced between seams with ribs 3/4" wide x 1" high at a maximum rib pitch of 8-1/2 inches.

Aluminized steel spiral rib pipe, type 2 (ASSRP) is available in the same sizes as galvanized steel spiral rib and will support the same fill heights (the aluminizing is simply a replacement coating for zinc galvanizing that allows thinner steel to be placed in certain corrosive environments. See Figure 855.3A for the acceptable pH and resistivity ranges for placement of aluminized steel pipes). Tables 856.3E, F & G give the maximum height of overfill for steel spiral rib pipe constructed under the acceptable methods contained in the Standard Specifications and essentials discussed in Index 829.2.

852.5 Corrugated Aluminum Pipe, Aluminum Spiral Rib Pipe and Pipe Arches

Corrugated aluminum pipe, aluminum spiral rib pipe and pipe arches are available in the diameters and arch shapes as indicated on the maximum height of cover tables. For larger diameters, arch spans or special shapes see Index 852.6. Corrugated aluminum pipe and pipe arches are available in various corrugation profiles with helical and annular corrugations. Helical corrugated pipe must be specified if anticipated heights of cover exceed the tabulated values for annular corrugated pipe. Non-standard pipe diameters and arch sizes are also available. Aluminum spiral rib pipe is similar to spiral rib steel and is available in several helical corrugation patterns.

(1) *Hydraulics.* Corrugated aluminum pipe comes in various corrugated profiles. Annular and helical corrugated aluminum pipe configurations are applicable in the situations where velocity reduction is important or if a culvert is being designed with an inlet control condition. Spiral rib pipe, on the other hand, may be more appropriate for use in stormdrain situations or if a culvert is being designed with an outlet control condition. Spiral rib pipe has a lower roughness coefficient (Manning's “n”) than other corrugated metal pipe profiles.

(2) *Durability.* Aluminum culverts or stormdrains may be specified as an alternate culvert material. When a 50-year maintenance-free service life of aluminum pipe is required the pH and minimum resistivity, as determined by California Test Method 643, must be known and the following conditions met:

   (a) The pH of the soil, backfill, and effluent is within the range of 5.5 and 8.5, inclusive. Bituminous coatings are not recommended for corrosion protection or abrasion resistance. Abrasive potential must be estimated from bed material that is present and anticipated flow velocities. Refer to Index 855.1 for a discussion of maintenance-free service life and Index 855.2 Abrasion, and Index 855.3 Corrosion prior to selecting aluminum as an allowable alternate.

(b) The minimum resistivity of the soil, backfill, and effluent is 1500 ohm-cm or greater.

(c) Aluminum culverts should not be installed in an environment where other aluminum culverts have exhibited significant distress, such as extensive perforation or loss of invert, for whatever reason, apparent or not.

(d) Aluminum may be considered for side drains in environments having the following parameters:

- When pH is between 5.5 and 8.5 and the minimum resistivity is between 500 and 1500 ohm-cm.
- When pH is between 5.0 and 5.5 or between 8.5 and 9.0 and the minimum resistivity is greater than 1500 ohm-cm.

For these conditions, the Corrosion Technology Branch in METS should be contacted to confirm the advisability of using aluminum on specific projects.

(e) Aluminum must not be used as a section or extension of a culvert containing steel sections.

(3) *Strength Requirements.* The strength requirements for corrugated aluminum pipe and pipe arches fabricated under the acceptable methods contained in the Standard Specifications, are given in Tables 856.3H, I & J. For aluminum spiral rib pipe, see Tables 856.3K & L.

(a) Design Standards.

- Corrugation Profiles - Corrugated aluminum pipe and pipe arches are available in 2⅔" x ½" and 5" x 1" profiles with helical or annular corrugations. Aluminum spiral rib pipe is available in a ¾" x ¾" x 7½" or a ¾" x 1" x 11½" helical corrugation profile.
- Metal thickness - Corrugated aluminum pipe and pipe arches are available in the thickness as indicated on Tables 856.3H, I & J. Where a maximum overfill is not listed on these tables, the pipe or pipe arch is not normally available in that thickness. Aluminum spiral rib pipe are available in the thickness as indicated on Tables 856.3K & L.
- Height of Fill - The allowable overfill heights for corrugated aluminum pipe and pipe arches for various diameters and metal thicknesses are shown on Tables 856.3H, I & J. For aluminum spiral rib pipe, overfill heights are shown on Tables 856.3K, & L.

(4) *Shapes*. Corrugated aluminum pipe, aluminum spiral rib pipe and pipe arches are available in the diameters and arch shapes as indicated on the maximum height of cover tables. Helical corrugated pipe must be specified if anticipated heights of cover exceed the tabulated values for annular corrugated pipe.

For larger diameters, arch spans or special shapes, see Index 852.6. Non-standard pipe diameters and arch sizes are also available.

(5) *Invert Protection.* Invert protection of corrugated aluminum is not recommended.

(6) *Spiral Rib Aluminum.* Aluminum spiral rib pipe is fabricated using sheet aluminum and continuous helical lock seam fabrication as used for helical corrugated metal pipe. The manufacturing complies with Section 66, “Corrugated Metal Pipe,” of the Standard Specifications, except for profile and fabrication requirements. Aluminum spiral rib pipe is fabricated with either: three rectangular ribs spaced midway between seams with ribs 3/4" wide x 3/4" high at a maximum rib pitch of 7-1/2 inches, two rectangular ribs and one half-circle rib equally spaced between seams with ribs 3/4" wide x 1" high at a maximum rib pitch of 11-1/2 inches with the half-circle rib diameter spaced midway between the rectangular ribs, or two rectangular ribs equally spaced between seams with ribs 3/4" wide x 1" high at a maximum rib pitch of 8-1/2 inches. Figure 855.3A should be used to determine the limitations on the use of spiral rib aluminum pipe for the various levels of pH and minimum resistivity.

852.6 Structural Metal Plate

(1) *Pipe and Arches*. Structural plate pipes and arches are available in steel and aluminum for the diameters and thickness as shown on Tables 856.3M, N, O & P.

(2) *Strength Requirements*.

(a) Design Standards.

- Corrugation Profiles - Structural plate pipe and arches are available in a 6" x 2" corrugation for steel and a 9" x 2½" corrugation profile for aluminum.
- Metal Thickness - structural plate pipe and pipe arches are available in thickness as indicated on Tables 856.3M, N, O & P.
- Height of Fill - The allowable height of cover over structural plate pipe and pipe arches for the available diameters and thickness are shown on Tables 856.3M, N, O & P.

Where a maximum overfill is not listed on these tables, the pipe or arch size is not normally available in that thickness.

(b) Basic Premise. To properly use the above mentioned tables, the designer should be aware of the premises on which the tables are based as well as their limitations. The design tables presuppose:

- That bedding and backfill satisfy the terms of the Standard Specifications, the conditions of cover, and pipe or arch size required by the plans and the essentials of Index 829.2.
- That a small amount of settlement will occur under the culvert, equal in magnitude to that of the adjoining material outside the trench.

(c) Limitations. In using the tables, the following restrictions should be kept in mind.

- The values given for each size of structural plate pipe or arch constitute the maximum height of overfill or cover over the pipe or arch for the thickness of metal and kind of corrugation.
- The thickness shown is the structural minimum. For steel pipe or pipe arches, where abrasive conditions are anticipated, additional metal thickness for the invert plate(s) or a paved invert should be provided when required to fulfill the design service life requirements. Table 855.2C may be used. See Index 855.2 Abrasion and Tables 855.2A, 855.2D and 855.2F.
- Where needed, adequate provisions for corrosion resistance must be made to achieve the required design service life called for in the references mentioned herein.
- Tables 856.3M & P show the limit of heights of cover for structural plate arches based on the supporting soil sustaining a bearing pressure of 3 tons per square foot at the corners.

(d) Special Designs. If the height of overfill exceeds the tabular values, or if the foundation investigation reveals that the supporting soil will not develop the bearing pressure on which the overfill heights for structural plate pipe or pipe arches are based, a special design prepared by DES - Structures Design is required.

(3) *Arches*. Design details with maximum allowable overfills for structural plate arches, with cast in place concrete footings may be obtained from DES - Structures Design.

(4) *Vehicular Underpasses*. Design details with maximum allowable overfills for structural plate vehicular underpasses with spans from 12 feet 2 inches to 20 feet 4 inches, inclusive, are given in the Standard Plans. These designs are based on bearing soil pressures from 1.4 tons per square foot to 5.8 tons per square foot.

(5) *Special Shapes*.

(a) Long Span. (Text Later)

- Arch

- Low Profile Arch
- High Profile Arch

(b) Ellipse. (Text Later)

- Vertical
- Horizontal

(6) *Tunnel Liner Plate.* The primary applications for tunnel liner plate include lining large structures in need of a structural repair, or culvert installations through an existing embankment that can be constructed by conventional tunnel methods. Typically, tunnel liner plate is not used for direct burial applications where structural metal plate pipe is recommended. DES - Structures Design will prepare designs upon request. See Index 853.7 for structural repairs.

852.7 Plastic Pipe

Plastic pipe is a generic term which currently includes two independent materials; the Standard Specifications states plastic pipe shall be made of either high density polyethylene (HDPE) or polyvinyl chloride (PVC) material. See Index 852.7(2)(a) Strength Requirements for allowed materials and wall profile types.

(1) *Durability.* Caltrans standards regarding the durability of plastic pipe are based on the long term performance of its material properties. Both forms of plastic pipe culverts (HDPE and PVC) exhibit good abrasion resistance and are virtually corrosion free. See Index 855.2 Abrasion and Index 855.5 Fire. Also, see Tables 855.2A, 855.2E and 855.2F. The primary environmental factor currently considered in limiting service life of plastic materials is ultraviolet (UV) radiation, typically from sunlight exposure. While virtually all plastic pipes contain some amount of UV protection, the level of protection is not equal. Polyvinyl chloride resins used for pipe rarely incorporate UV protection (typically Titanium Dioxide) in amounts adequate to offset long term exposure to direct sunlight. Therefore, frequent exposure (e.g., cross culverts with exposed ends) can lead to brittleness and such situations should be avoided. Conversely, testing performed to date on HDPE products conforming to specification requirements for inclusion of carbon black have exhibited adequate UV resistance. PVC pipe exposed to freezing conditions can also experience brittleness and such situations should be avoided if there is potential for impact loadings, such as maintenance equipment or heavy (3" or larger) bedload during periods of freeze. Plastic pipes can also fail from long term stress that leads to crack growth and from chemical degradation. Improvements in plastic resin specifications and testing requirements has led to increased resistance to slow crack growth. Inclusion of anti-oxidants in the material formulation is the most common form of delaying the onset of chemical degradation, but more thorough testing and assessment protocols need to be developed to more accurately estimate long term performance characteristics and durability.

(2) *Strength Requirements.*

(a) Design Standards

- Materials - Plastic pipe shall be either Type C (corrugated exterior and interior) corrugated polyethylene pipe, Type S (corrugated exterior and smooth interior) corrugated polyethylene pipe, ribbed profile wall polyethylene pipe, corrugated polyvinyl chloride pipe, or ribbed polyvinyl chloride pipe.
- Height of Fill - The allowable overfill heights for plastic pipe for various diameters are shown in Tables 856.4 and 856.5.

852.8 Special Purpose Types

(1) *Smooth Steel.* Smooth steel (welded) pipe can be utilized for drainage facilities under conditions where corrugated metal or concrete pipe will not meet the structural or design service life requirements, or for certain jacked pipe operations (e.g., auger boring).

(2) *Composite Steel Spiral Rib Pipe.* Composite steel spiral rib pipe is a smooth interior pipe with efficient hydraulic characteristics. See Table 852.1.

Composite steel spiral rib pipe with its interior polyethylene liner exhibits good abrasion resistance and also resists waterside corrosion found in a typical stormdrain or culvert environment. The exterior of the pipe is protected with a polyethylene film, which offers resistance to corrosive backfills. The pipe will meet a 50 - year maintenance-free service life under most conditions.

(3) *Proprietary Pipe.* See Indexes 110.10 and 601.5(3) for further discussion and guidelines on the use of proprietary items.

Topic 853 - Pipe Liners and Linings for Culvert Rehabilitation

853.1 General

This topic discusses alternative pipe liner and pipe lining materials specifically intended for culvert repair and does not include materials used for Trenchless Excavation Construction (e.g., pipe jacking, pipe ramming, augur boring), joint repair, various types of grouting, or standard pipe materials that are presented elsewhere in Chapter 850 and in the Standard Plans and Standard Specifications.

Many new products and techniques have been developed that often make complete replacement with open cut as shown in the Standard Plans unnecessary. When used appropriately, these new products and techniques can benefit the Department in terms of increased mobility, cost, and safety to both the public and contractors. Design Information Bulletin 83 (DIB 83) outlines a collection of procedures that are cost-effective for their location and that will meet the needs of their particular area and supplements Topic 805. Use the following link; http://www.dot.ca.gov/hq/oppd/dib/dib83-01.htm

853.2 Caltrans Host Pipe Structural Philosophy

In general, if the host (i.e., existing) pipe cannot be made capable of sustaining design loads, it should be replaced rather than rehabilitated. This is a conservative approach and when followed eliminates the need to make detailed evaluations of the liners ability to effectively accept and support dead and live loads. Prior to making the decision whether or not to rehabilitate the culvert and/or which method to choose, a determination of the structural integrity of the host pipe must be made. Existing voids within the culvert backfill or in the base material under the existing culvert identified either by Maintenance (typically as part of their culvert management system) or already noted in the Geotechnical Design Report, should be filled with grout to re-establish its load carrying capability prior to rehabilitating any type of culvert. Therefore, structural considerations for pipe liners are generally limited to their ability to withstand construction handling and/or grouting pressures. When a structural repair is needed, contact Underground Structures within DES – Structures Design. See Index 853.7.

853.3 Problem Identification and Coordination

Before various alternatives for liners or linings can be selected, the first step following a site investigation which may include taking soil and water samples and pipe wall thickness measurements, is to determine the actual cause of the problem. Relative to Caltrans host pipe structural philosophy, the host pipe may be in need of stabilization, rehabilitation or replacement. Further, it will need to be determined if the structure is at the end of its maintenance-free service life, whether it has been damaged by mechanical abrasion, or corrosion (or both) and if there are any changes to the hydrology or habitat (e.g. fish passage). To make these determinations, the Project Engineer should coordinate with the District Maintenance Culvert Inspection team, Hydraulics and Environmental units. Further assistance may be needed from Geotechnical Design, the Corrosion Technology Branch within DES, Underground Structures and/or Structures Maintenance within DES. Prior to a comprehensive inspection either by trained personnel or camera, it may also be necessary to first clean out the culvert. Problem identification and assessment, and coordination with Headquarters and DES, is discussed in greater detail in DIB 83. Use the following link; http://www.dot.ca.gov/hq/oppd/dib/dib83-01-7.htm#7-1-6

853.4 Alternative Pipe Liner Materials

Similar to the basic policy in Topic 857.1 for alternative pipes, when two or more liner materials meet the design service life and minimum thickness requirements for various materials that are outlined under Topic 855, as well as hydraulic requirements, the plans and specifications should provide for alternative pipe liners to allow for optional selection by the contractor. A table of allowable alternative pipe liner materials for culverts and drainage systems is included as Table 853.1A. This table also identifies the various diameter range limitations and whether annular space grouting is needed. Sliplining consists of sliding a new culvert inside an existing distressed culvert as an alternative to total replacement. See DIB No 83; http://www.dot.ca.gov/hq/oppd/dib/dib83-01-6.htm#6-1-3-1.

The plastic pipeliners listed in the notes under Table 853.1A are installed as slipliners, however, other standard pipe types that are described in Topic 852 (e.g., metal), may be equally viable as material options to be added as sliplining alternatives.

Table 853.1A
Allowable Alternative Pipe Liner Materials

Allowable Alternatives	Diameter Range (1)	Annular Space Grouting
PP (2)	15" – 120"	Yes
CIPP	8" – 96"	No
DRHDPEPL	18" – 30"	No
MSWPVCPLED	6" – 30"	No
SWPVCPLFD	21" – 108"	Yes

Abbreviations:

PP – Plastic Pipe (sliplining)
CIPP – Cured in Place Pipe
DRHDPEPL – Deformed/Reformed HDPE Pipe Liner
SWPVCPLFD – Spiral Wound PVC Pipe Liner (Fixed Diameter)
MSWPVCPLED – Machine Spiral Wound PVC Pipe Liner (Expandable Diameter)

Note:

(1) Headquarters approval needed for pipe liner diameters 60 inches or larger. Diameter range represents liners only, not Caltrans standard pipe.

(2) At the Contractor's option, plastic pipeliners shall be either:

- Ribbed polyvinyl chloride (PVC) drain pipe conforming to the provisions in Section 64, “Plastic Pipe,” of the Standard Specifications; or
- Ribbed profile wall high density polyethylene (HDPE) pipe conforming to the provisions in Section 64, “Plastic Pipe,” of the Standard Specifications; or
- Type S or Type C corrugated high density polyethylene (HDPE) pipe conforming to the provisions in Section 64, “Plastic Pipe,” of the Standard Specifications; or
- Standard Dimension Ratio (SDR) 35 polyvinyl chloride (PVC) pipe conforming to the requirements in AASHTO Designation: M 278 and ASTM Designation: F 679; or
- Polyvinyl chloride (PVC) closed profile wall pipe conforming to the requirements in ASTM Designation: F 1803, F 794 (Series 46); or
- Polyvinyl chloride (PVC) dual wall corrugated pipe conforming to the requirements in ASTM Designation: F 794 (Series 46), F 949; or
- High density polyethylene (HDPE) solid wall pipe conforming to the requirements in AASHTO M 326 and ASTM Designation: F 714; or
- Large diameter high density polyethylene (HDPE) closed profile wall pipe conforming to the requirements in ASTM Designation: F 894.

Table 853.1B provides a guide for plastic pipeliner selection in abrasive conditions to achieve a 50-year maintenance-free service life.

For further information on sliplining using plastic pipe liners including available dimensions and stiffness, see DIB 83. Use the following link: http://www.dot.ca.gov/hq/oppd/dib/dib83-01-6.htm#6-1-3-1-1

853.5 Cementitious Pipe Lining

This method may be used to line corroded corrugated steel pipes ranging from 12 inches to a maximum of 48 inches diameter and involves lining an existing culvert with concrete, shotcrete or mortar using a lining machine. Regardless of type of cementitious material used, the resulting lining is a minimum of one inch thick when measured over the top of corrugation crests and has a smooth surface texture. As with other liners, the pipes must first be thoroughly cleaned and dried. For diameters between 12 and 24 inches, the cement mortar is applied by robot. The mortar is pumped to a head, which rotates at high speed using centrifugal force to place the mortar on the walls. A conical-shaped trowel attached to the end of the machine is used to smooth the walls. The maximum recommended length of small-diameter pipe that can be lined using this method is approximately 650 feet. Although this method will line larger diameter pipes, it is mostly appropriate for non-human entry pipes (less than 30 inches). Generally, most problems with steel pipe are limited to the lower 180 degrees, therefore, in larger diameter metal pipes where human entry is possible, invert paving may be all that is required. See Index 853.6.

853.6 Invert Paving with Concrete

(1) *Existing Corrugated Metal Pipe (CMP).* One of the most effective ways to rehabilitate corroded and severely deteriorated inverts of CMP that are large enough for human entry (with equipment) is by paving them with reinforced concrete using Class 1, Class 2 or shotcrete with a minimum compressive strength of 6000 psi. See index 110.12 Tunnel Safety Orders. Generally, this method is feasible for pipes 48 inches in diameter and larger. If abrasion is present, the aggregate source should be harder material than the streambed load and have a high durability index (consult with District Materials Branch for sampling and recommendation). The maximum grading specified (1.5 inch) for coarse aggregate may need to be modified if the concrete must be pumped. The abrasion resistance of cementitious materials is affected by both its compressive strength and hardness of the aggregate. There is a correlation between decreasing the water/cement ratio, increasing compressive strength and increasing abrasion resistance. Therefore, where abrasion is a significant factor, the lowest practicable water/cement ratios and the hardest available aggregates should be used.

Paving thickness will range from 2 inches to 13 inches depending on abrasiveness of site based on Table 855.2A, and paving limits typically vary from 90 to 120 degrees for the internal angle. See Index 855.2 and Table 855.2F. Note that in Table 855.2F cementitious concrete is not recommended for extremely abrasive conditions (Level 6 in Table 855.2A). For extremely abrasive conditions alternative materials are recommended such as abrasion resistant concrete (calcium aluminate), steel plate or adding RSP. If hydraulically feasible, a flattened invert design may be warranted. Consult the District Hydraulic Branch for a recommendation.

Where there is significant loss of the pipe invert, it may be necessary to tie the concrete to more structurally sound portions of the pipe wall in order to transfer compressive thrust of culvert walls into the invert slab to create a "mechanical" connection using welding studs, angle iron or by other means. When a mechanical connection is used, paving limits may vary up to 180 degrees for the internal angle. These types of repairs should be treated as a special design and consultation with the Headquarters Office of Highway Drainage Design within the Division of Design and the Underground Structures unit of Structures Design within the Division of Engineering Services (DES) is advised. Depending on the size of the culvert being paved, pipes with significant invert loss often also have a significant loss of structural backfill with voids present. Where large voids are present, consultation with Geotechnical Services within the Division of Engineering Services (DES) is advised to develop a grouting plan.

See DIB 83 for some invert paving case studies using the following link: http://www.dot.ca.gov/hq/oppd/dib/dib83-01-12.htm#h

(2) *Existing RCB and RCP.* For existing reinforced concrete boxes (RCB) and reinforced concrete pipes (RCP) with worn inverts and exposed reinforcing steel (generally from abrasive bedloads), the same paving thickness considerations outlined under Index 853.6(1) will apply. However, depending on the structural condition, the existing steel reinforcement may need to be augmented.

Table 853.1B

Guide for Plastic Pipeliner Selection in Abrasive Conditions(2) to Achieve 50 Years of Maintenance-Free Service Life

		Abrasion Level(1)		
Material		4	5	6
Ribbed PVC (AASHTO M 304)		21"– 48"	-	-
Type S corrugated polyethylene pipe		-	-	-
Standard Dimension Ratio (SDR) 35 PVC	(46 psi)	4" – 48"	12"- 48"	36"– 48"
	(75 psi)	18" – 48"	18" – 48"	30" – 48"
Note: OD's listed	(115 psi)	18" – 48"	18" – 48"	27" – 48"
PVC closed profile wall (ASTM F 1803)		18" – 60"	42"– 60"	-
Corrugated PVC (ASTM F 794 & F 949)	(46 psi)	18" – 36"	-	-
	(115 psi)	15"	-	-
Standard Dimension Ratio (SDR) HDPE conforming to:	SDR 41	10" – 63"	36" – 63"	-
	SDR 32.5	8" – 63"	30" – 63"	-
	SDR 26	6" – 63"	24" – 63"	-
AASHTO M 326 and ASTM Designation: F 714	SDR 21	5" – 63"	20" – 63"	54" – 63"
	SDR 17	5" – 55"	16" – 55"	42" – 55"
	SDR 15.5	5" – 48"	14" – 48"	42" – 48"
	SDR 13.5	5" – 42"	12" – 42"	34" – 42"
	SDR 11	5" – 36"	10" – 36"	28" - 36"
Note: OD's listed	SDR 9	5" – 24"	8" – 24"	22"
Polyethylene (PE) large diameter profile wall sewer and drain pipe as specified in ASTM F 894	RSC 160	18" – 120"	120"	-
Note: RSC = Ring Stiffness Class	RSC 250	33" – 108"	96" – 108"	-

Notes:

(1) See Tables 855.2A and 855.2F for Abrasion Level Descriptions and minimum thickness.

(2) No restrictions for Abrasion Levels 1 through 3.

Consultation with Structures Maintenance and Underground Structures within DES is recommended.

(3) *Existing Plastic Pipe.* Generally, concrete invert paving is not feasible for plastic pipes because the cement will not adhere to plastic. However, it may be possible to create a "mechanical" connection by other means but these types of repairs should be treated as a special design and consultation with the Headquarters Office of Highway Drainage Design within the Division of Design and the Underground Structures unit of Structures Design within the Division of Engineering Services (DES) is advised.

853.7 Structural Repairs with Steel Tunnel Liner Plate

Cracks in RCP greater than 0.1 inch in width and flexible metal pipes with deflections beyond 10 – 12 percent may indicate a serious condition. When replacement is not an option for existing human entry pipes in need of structural repair, an inspection by Structures Maintenance and a structural analysis by Underground Structures within DES are recommended. Further assistance may be needed from Geotechnical Design and/or the Corrosion Unit within DES.

Two flange or four flange steel tunnel liner plate can be specially designed by Underground Structures within DES as a structural repair to accommodate all live and dead loads. The flange plate lap joints facilitate internal bolt connections (structural metal plate requires access to both sides). After the rings have been installed, the annular space between the liner plates and the host pipe is grouted.

Topic 854 - Pipe Connections

854.1 Basic Policy

The Standard Specifications set forth general performance requirements for transverse field joints in all types of culvert and drainage pipe used for highway construction.

Table 857.2 indicates the alternative types of joints that are to be specified for different arch and circular pipe installations with regard to joint strength. The two joint strength types specified for culvert and drainage systems are identified as "standard" and "positive."

(1) *Joint Strength.* Joint strength is to be designated on the culvert list.

(a) Standard Joints. The "standard" joint is usually for pipes or arches not subject to large soil movement or disjointing forces. These "standard" joints are satisfactory for ordinarily installations, where tongue and groove or simple slip type joints are typically used. The "standard" joint type is generally adequate for underdrains.

(b) Positive Joints. "Positive" joints are for more adverse conditions such as the need to withstand soil movements or resist disjointing forces. Examples of these conditions are steep slopes, sharp curves, and poor foundation conditions. See Index 829.2 for additional discussion. "Positive" joints should always be designated on the culvert list for siphon installations.

(c) Downdrain Joints. Pipe "downdrain" joints are designed to withstand high velocity flows, and to prevent leaking and disjointing that could cause failure.

(d) Joint Strength Properties. A description of the specified joint strength properties tabulated in Section 61 "Culvert and Drain Pipe Joints" of the Standard Specifications is as follows:

- Shear Strength. The shear strength required of the joint is expressed as a percentage of the calculated shear strength of the pipe at a transverse section remote from the joint. All joints, including any connections must be capable of transferring the required shear across the joint.
- Moment Strength. The moment strength required of the joint is expressed as a percent of the calculated moment capacity of the pipe on a transverse section remote from the joint.
- Tensile Strength. The tensile strength is that which resist the longitudinal force

which tends to separate (disjoint) adjacent pipe sections.

- Joint Overlap.

  Integral Preformed Joint. The Joint overlap is the amount of protection of one culvert barrel into the adjacent culvert barrel by the amount specified for the size of pipe designated. The amount of required overlap will vary based on several factors (material type, diameter, etc.) and is designated on the Standard Plans and/or Standard Specifications.

  Any part of an installed joint that has less than ¼ inch overlap will be considered disjointed. Whenever the plans require that the culvert be constructed on a curve, specially manufactured sections of culvert will be required if the design joint cannot meet the minimum ¼ inch overlap requirement after the culvert section is placed on the specified curve.

- Sleeve Joints. The joint overlap is the minimum sleeve width (typically defined by the width of a coupling band) required to engage both the culvert barrels which are abutted to each other.

(2) *Joint Leakage.* The ability of a pipe joint to prevent the passage of either soil particles or water defines its soiltightness or watertightness. These terms are relative and do not mean that a joint will be able to completely stop the movement of soil or water under all conditions. Any pipe joint that allows significant soil migration (piping) will ultimately cause damage to the embankment, the roadway, or the pipe itself. Therefore, site conditions, such as soil particle size, presence of groundwater, potential for pressure flow, etc., must be evaluated to determine the appropriate joint requirement. Other than solvent or fusion welded joints, almost all joints can exhibit some amount of leakage. Joint performance is typically defined by maximum allowable opening size in the joint itself or by the ability to pass a standardized pressure test. The following criteria should be used, with the allowable joint type(s) indicated on the project plans:

- Normal Joint. Many pipe joint systems are not defined as either soiltight or watertight. However, for the majority of applications, such as culverts or storm drains placed in well graded backfill and surrounding soils containing a minimum of fines; no potential for groundwater contact; limited internal pressure, hydraulic grade line below the pavement grade, etc., this type of joint is acceptable. All currently accepted joint types will meet or exceed "Normal Joint" requirements. The following non-gasketed joint types should not be used beyond the "Normal Joint" criteria range:

<u>CMP</u>	-Annular -Hat -Helical -Hugger -2-piece Integral Flange -Universal
<u>PLASTIC</u>	-Split Coupler -Bell/Spigot

- Soiltight Joint. This category includes those joints which would provide an enhanced level of security against leakage and soil migration over the normal joint. One definition of a soiltight joint is contained in Section 26.4.2.4(e) of the AASHTO Standard Specifications for Highway Bridges. In part, this specification requires that if the size of the opening through which soil might migrate exceeds 1/8 inch, the length of the channel (length of path along which the soil particle must travel, i.e., the coupling length) must exceed 4 times the size of the opening. Alternatively, AASHTO allows the joint to pass a hydrostatic test (subjected to approx. 4.6 feet of head) without leaking to be considered soiltight. Typical pipe joints that can meet this criteria are:

<u>RCP and NRCP</u>	-Flared Bell -Flushed Bell -Steel Joint-Flush Bell

-Single or Double Offset Design (Flared or Flushed Bell)
-Double Gasket
-Tounge and Groove*
-Self-Centering T & G*

CMP and SSRP	-Annular w/gasket -Hat w/gasket -Helical w/gasket -Hugger w/gasket -2-piece Int. Fl. w/gasket -Universal w/gasket
CSSRP	-Cuffed end w/gasket
PLASTIC	-Split Coupler w/gasket (premium) -Bell/Spigot w/gasket

* Where substantial differential settlement is anticipated, would only meet Normal Joint criteria.

Where soil migration is of concern, but leakage rate is not, a soiltight joint can be achieved in most situations by external wrapping of the joint area with filter fabric (see Index 831.4). Joints listed under both the normal joint and soiltight joint categories, with a filter fabric wrap, would be suitable in these conditions and would not require a gasket or sealant. In many cases, fabric wrapping can be less expensive than a rubber gasket or other joint sealant. Coordination with the District Materials Unit is advised to verify that standard filter fabric described in Standard Specification Section 88-1.03 is of sufficient strength to withstand forces applied during construction (heavier fabric may be specified) and that fabric will effectively screen fine soil particles from passage.

- Watertight Joint. Watertight joints are specified when the potential for soil erosion or infiltration/exfiltration must be restricted, such as for downdrains, culverts in groundwater zones, etc. Watertight joint requirements are typically met by the use of rubber gasket materials as indicated in the Standard Specifications. The watertight certification test described in Standard Specification Section 61 requires that no leakage occur when a joint is tested for a period of 10 minutes while subjected to a head of 10 feet over the crown of the pipe. This is a test that is typically performed in a laboratory under optimal conditions not typical of those found in the field. Where an assurance of watertightness is needed, a field test should be specified. Designers should be aware that field tests can be relatively expensive, and should only be required if such assurance is critical. A field leakage rate in the range of 700 gallons to 1,000 gallons per inch of nominal diamter per mile of pipe length per day, with a hydrostatic head of 6 feet above the crown of the pipe, is not unusual for joints that pass the watertight certification test, and is sufficiently watertight for well graded, quality backfill conditions. Where conditions are more sensitive, a lower rate should be specified. Rates below 50 to 100 gallons per inch per mile per day are difficult to achieve and would rarely be necessary. For example, sanitary sewers are rarely required to have leakage rates below 200 gallons per inch per mile per day, even though they have stringent health and environmental restrictions. Field hydrostatic tests are typically conducted over a period of 24 hours or more to establish a valid leakage rate. Designers should also be aware that non-circular pipe shapes (CMP pipe arches, RCP oval shapes, etc.) should not be considered watertight even with the use of rubber gaskets or other sealants due to the lack of uniform compression around the periphery of the joint. Additionally, watertight joints specified for pressure pipe or siphon applications must meet the requirements indicated in Standard Specification Sections 65 and 66. Pipe joints that meet Standard Specification Section 61 water-tightness performance criteria are:

RCP and NRCP	-Flared Bell -Flushed Bell

	-Steel Joint-Flush Bell -Single or Double Offset Design (Flared or Flushed Bell) -Double Gasket
CMP and SSRP	-Hugger Bands (H-10, 12) w/gasket and double bolt bar -Annular Band w/gasket -Two Piece Integral Flange w/sleeve-type gasket*
PLASTIC	-Bell/Spigot w/gasket

* Acceptable as a watertight pipe only in downdrain applications and in 6, 8 and 10 inch diameters. Factory applied sleeve-type gaskets are to be used instead of O-ring or other sealants.

Table 854.1 provides information to help the designer select the proper joint under most conditions.

Topic 855 - Design Service Life

855.1 Basic Concepts

The prediction of design service life of drainage facilities is difficult because of the large number of variables, continuing changes in materials, wide range of environments, and use of various protective coatings. The design service life of a drainage facility is defined as the expected maintenance-free service period of each installation. After this period, it is anticipated major will be needed for the facility to perform as originally designed for further periods.

For all metal pipes and arches that are listed in Table 857.2, maintenance-free service period, with respect to corrosion, abrasion and/or durability, is the number of years from installation until the deterioration reaches the point of perforation at any location on the culvert (See Figures 855.3A, 855.3B, and Tables 855.2D and 855.2F). AltPipe can be used to estimate service life of all circular metal pipe. See Index 857.2 Alternative Pipe Culvert Selection Procedure Using AltPipe.

For reinforced concrete pipe (RCP), box (RCB) and arch (RCA) culverts, maintenance-free service period, with respect to corrosion, abrasion and/or durability, is the number of years from installation until the deterioration reaches the point of exposed reinforcement at any point on the culvert. AltPipe can be used to estimate service life of reinforced concrete pipe (RCP), but not RCB, RCA or NRCP. See Index 857.2 Alternative Pipe Culvert Selection Procedure Using AltPipe.

For non-reinforced concrete pipe culverts (NRCP), maintenance-free service period, with respect to corrosion, abrasion and/or durability, is the number of years from installation until the deterioration reaches the point of perforation or major cracking with soil loss at any point on the culvert.

For plastic pipe, maintenance-free service period, with respect to corrosion, abrasion, and long term structural performance, is the number of years from installation until the deterioration reaches the point of perforation at any location on the culvert or until the pipe material has lost structural load carrying capacity typically represented by wall buckling or excessive deflection/deformation. AltPipe can be used to estimate service life of all plastic pipe. See Index 857.2 Alternative Pipe Culvert Selection Procedure Using AltPipe. All types of culverts are subject to deterioration from corrosion, or abrasion, or material degradation.

Corrosion may result from active elements in the soil, water and/or atmosphere. Abrasion is a result of mechanical wear and depends upon the frequency, duration and velocity of flow, and the amount and character of bedload. Material degradation may result from material quality, UV exposure, or long term material structural performance.

To assure that the maintenance-free service period is achieved, alternative metal pipe may require added thickness and/or protective coatings. Concrete pipe may require extra thickness of concrete cover over the steel reinforcement, high density concrete, using supplementary cementitious materials, epoxy coated reinforcing steel, and/or protective coatings. Means for estimating the maintenance-free service life of pipe, and techniques for extending the useful life of pipe materials are discussed in more detail in Topic 852.

Table 854.1
Joint Leakage Selection Criteria

JOINT TYPE ⇒ ⇓ SITE CONDITIONS	"NORMAL" JOINT	"SOIL TIGHT" JOINT	"WATER TIGHT" JOINT
SOIL FACTORS			
Limited potential for soil migration (e.g., gravel, medium to coarse sands, cohesive soil)	X	X	X
Moderate potential for soil migration (e.g., fine sands, silts)	X(1)	X	X
High potential for soil migration (e.g., very fine sands, silts of limited cohesion)		X(1)	X(1)
INFILTRATION / EXFILTRATION			
No concern over either infiltration or exfiltration.	X	X	X
Infiltration or exfiltration not permitted (e.g., potential to contaminate groundwater, contaminated plume could infiltrate)			X(2)
HYDROSTATIC POTENTIAL			
Installation will rarely flow full. No contact with groundwater.	X	X	X
Installation will occasionally flow full. Internal head no more than 10 feet over crown. No potential groundwater contact.		X	X
Installation may or may not flow full. Internal head no more than 10 feet over crown. May contact groundwater.			X
Possible hydrostatic head (internal or external) greater than 10 feet, but less than 25 ft(3).			X(2)

Notes:
"X" indicates that joint type is acceptable in this application. The designer should specify the most cost-effective option.
(1) Designer should specify filter fabric wrap at joint. See Index 831.4.
(2) Designer should consider specifying field watertightness test.
(3) Pipe subjected to hydrostatic heads greater than 25 ft should have joints designed specifically for pressure applications.

The design service life for drainage facilities for all projects should be as follows:

(1) Culverts, Drainage Systems, and Side Drains.

(a) Roadbed widths greater than 28 feet - 50 years.

(b) Greater than 10 feet of cover - 50 years.

(c) Roadbed widths 28 feet or less and with less than 10 feet of cover - 25 years.

(d) Installations under interim alignment - 25 years.

(2) Overside Drains.

(a) Buried more than 3 feet- 50 years.

(b) All other conditions, such as on the surface of fill slopes - 25 years.

(3) Subsurface Drains.

(a) Underdrains within roadbed - 50 years.

(b) Underdrains outside of roadbed - 25 years.

(c) Stabilization trench drains - 50 years.

In case of conflict in the design service life requirements between the above controls, the highest design service life is required except for those cases of interim alignment with more than 10 feet of cover. For temporary construction, a lesser design service life than that shown above is acceptable.

Where the above indicates a minimum design service life of 25 years, 50 years may be used. For example an anticipated change in traffic conditions or when the highway is considered to be on permanent alignment may warrant the higher design service life.

855.2 Abrasion

All types of pipe material are subject to abrasion and can experience structural failure around the pipe invert if not adequately protected. Abrasion is the wearing away of pipe material by water carrying sands, gravels and rocks (bed load) and is dependent upon size, shape, hardness and volume of bed load in conjunction with volume, velocity, duration and frequency of stream flow in the culvert. For example, at independent sites with a similar velocity range, bedloads consisting of small and round particles will have a lower abrasion potential than those with large and angular particles such as shattered or crushed rocks. Given different sites with similar flow velocities and particle size, studies have shown the angularity and/or volume of the material may have a significant impact to the abrasion potential of the site. Likewise, two sites with similar site characteristics, but different hydrologic characteristics, i.e., volume, duration and frequency of stream flow in the culvert, will probably also have different abrasion levels.

In Table 855.2A six abrasion levels have been defined to assist the designer in quantifying the abrasion potential of a site. The designer is encouraged to use the guidelines provided in Table 855.2A in conjunction with Table 855.2B "Bed Materials Moved by Various Flow Depths and Velocities" and the abrasion history of a site (if available) to achieve the required service life for a pipe, coating or invert lining material. Sampling of the streambed materials generally is not necessary, but visual examination and documentation of the size and shape of the materials in the streambed and estimating the average stream slope will provide the designer data needed to determine the expected level of abrasion. Where an existing culvert is in place, the condition of the invert and estimated combined wear rate due to abrasion and corrosion based on remaining pipe thickness measurements or if it is known approximately when first perforation occurred (steel pipe only), should always be used first. Figure 855.3B should be used to estimate the expected loss due to corrosion for steel pipe.

The descriptions of abrasion levels in Table 855.2A are intended to serve as general guidance only, and not all of the criteria listed for a particular abrasion level need to be present to justify defining a site at that level. For example, if there are increased velocities with minor bedload volumes, significantly higher velocities may be applicable to any of the lower three abrasion levels.

Table 855.2C constitutes a guide for estimating the added service life that can be achieved by coatings and invert paving of steel pipes based upon abrasion resistance characteristics. However, the table does not quantify added service life of coatings and paving of steel pipe based upon corrosion protection. In heavily abrasive situations, concrete inverts or other lining alternatives outlined in Table

855.2A should be considered. The guide values for years of added service life should be modified where field observations of existing installations show that other values are more accurate. The designer should be aware of the following limitations when using Table 855.2C:

- Channel Materials: If there is no existing culvert, it may be assumed that the channel is potentially abrasive to culvert if sand and/or rocks are present. Presence of silt, clay or heavy vegetation may indicate a non-abrasive flow.
- Flow velocities: The velocities indicated in the table should be compared to those generated by the 2-5 year return frequency flood.
- The abrasion levels represent all six abrasion levels presented in Table 855.2A however, levels 2 and 3 have been combined.

Table 855.2D constitutes a guide for anticipated wear (in mils/year) to metal pipe by abrasive channel materials. No additional abrasion wear is anticipated for steel for the lower three abrasion levels defined in Table 855.2A, because it is assumed that there is some degree of abrasion incorporated within California Test 643 and Figure 855.3B. Figure 855.3B, "Chart for Estimating Years to Perforation of Steel Culverts," is part of a Standard California Department of Transportation Test Method derived from highway culvert investigations. This chart alone is not used for determining service life because it does not consider the effects of abrasion or overfill; it is for estimating the years to the first corrosion perforation of the wall or invert of the CSP. Additional gauge thickness or invert protection may be needed if the thickness for structural requirements (i.e., for overfill) is inadequate for abrasion potential.

Table 855.2E indicates relative abrasion resistance properties of pipe and lining materials and summarizes the findings from "Evaluations of Abrasion Resistance of Pipe and Pipe Lining Materials Final Report FHWA /CA/TL-CA01-0173 (2007)". This report may be viewed at the following web address: http://www.dot.ca.gov/new/tech/researchreports/reports/2007/evaluation_of_abrasion_resistance_final_report.pdf. See Figure 855.1.

Figure 855.1
Abrasion Test Panels

Various culvert material test panels shown in Figure 855.1 after 1 year of wear at site with moderate to severe abrasion (velocities generally exceed 13 ft/s with heavy bedload).

Table 855.2F is based on Tables 855.2D and 855.2E and constitutes a guide for selecting the minimum material thickness of abrasive resistant invert protection for various materials to achieve 50 years of maintenance-free service life.

Structural metal plate pipe and arches provide a viable option for large diameter pipes (60 inches or larger) in abrasive environments because increased thickness can be specified for the lower 180 degrees or invert plates. If the thickness for structural requirements is inadequate for abrasion potential, it is recommended to apply the increased thickness to the lower 180 degrees of the pipe only. Arches, which have a relatively larger invert area than circular pipe, generally will provide a lower abrasion potential from bedload being less concentrated.

Under similar conditions, aluminum culverts will abrade between one and a half to three times faster than steel culverts. Therefore, aluminum culverts are not recommended where abrasive materials are present, and where flow velocities would encourage abrasion to occur. Culvert flow velocities that frequently exceed 5 feet per second where abrasive materials are present should be carefully evaluated prior to selecting aluminum as an allowable alternate. In a corrosive environment, Aluminum may display less abrasive wear than steel depending on the volume, velocity, size, shape, hardness and rock impact energy of the bed load. However, if it is deemed necessary to place aluminum pipe in abrasion levels 4 through 6 in Table 855.2C, contact Headquarters Office of State Highway Drainage Design for assistance. Invert protection (including concrete) for corrugated aluminum is not recommended.

Aluminized Steel (Type 2) can be considered equivalent to galvanized steel for abrasion resistance and therefore does not have the same limitations as aluminum in abrasive environments.

Concrete pipes typically counter abrasion through increased minimum thickness over the steel reinforcement, i.e., by adding additional sacrificial material. See Table 855.2F. However, there are significantly less limitations involved in increasing the invert thickness of RCB in the field verses increasing minimum thickness over the steel reinforcement of RCP in the plant. Therefore, RCP is typically not recommended in abrasive flows greater than 10 feet per second but may be considered for higher velocities if the bedload is insignificant (e.g. storm drain systems and most culverts smaller than 30 inches in diameter or abrasion levels 1 through 3 in Table 855.2C). Abrasion resistance for any concrete lining is dependent upon the thickness, quality, strength, and hardness of the aggregate and density of the concrete as well as the velocity of the water flow coupled with abrasive sediment content and acidity. Abrasion resistant concrete made from calcium aluminate provides much improved abrasion resistance over cementitious concrete and should be considered as a viable countermeasure in extremely abrasive conditions (i.e, velocity greater than 15 feet per second with heavy bedload). See Table 855.2F.

Plastic materials typically exhibit good abrasion resistance but service life is constrained by the manufactured thickness of typical pipe profiles. Both PVC and HDPE corrugated and ribbed pipe are limited for their use in moderate and heavy bedload abrasion conditions by the combined manufactured inner liner and corrugated wall thicknesses. For culvert rehabilitation, PVC and HDPE pipe slip lining products (e.g. solid wall HDPE) are viable options for applications in moderate and heavy bedload abrasion conditions (see Table 855.2A).

Table 855.2A can be used as a "preliminary estimator" of abrasion potential for material selection to achieve the required service life, however, it uses only two of the factors that are outlined above; bed load size and flow velocity. As discussed above, the other factors that are not used in the table should also be carefully considered. For example, under similar hydraulic conditions, heavy volumes of hard, angular sand may be more abrasive than small volumes of relatively soft, large rocks. Furthermore, two sites with similar site characteristics, but different hydrologic characteristics, i.e., volume, duration and frequency of stream flow in the culvert, will probably also have different abrasion levels. Table 855.2B can be used as a guide with Table 855.2A to determine the maximum size of material that can be moved through a pipe. Field observations of channel bed material both upstream and downstream from the pipe are extremely important for estimating the size range of transportable material in the channel.

Table 855.2A
Abrasion Levels and Materials

Abrasion Level	General Site Characteristics	Invert/Pipe Materials
Level 1	• Virtually no bed load with velocities less than 5 ft/s* * Where there are increased velocities with no bed load (e.g. urban storm drain systems or culverts ≤ 30" dia.), significantly higher velocities may be applicable to level 1	All pipe materials listed in Table 857.2 allowable for this level. No abrasive resistant protective coatings listed in Table 855.2C needed for metal pipe.
Level 2	• Bed loads of sand, silts, or clays regardless of volume • Velocities ≥ 3 ft/s and ≤ 8 ft/s** ** Where there are increased velocities with minor bed load volumes (e.g. urban storm drain systems or culverts ≤ 30" dia.), significantly higher velocities may be applicable to level 2	All allowable pipe materials listed in Table 857.2 with the following considerations: • Generally, no abrasive resistant protective coatings needed for steel pipe. • Polymeric, polymerized asphalt or bituminous coating or an additional gauge thickness of metal pipe may be specified if existing pipes in the same vicinity have demonstrated susceptibility to abrasion and thickness for structural requirements is inadequate for abrasion potential.
Level 3	• Moderate bed load volumes of sands and gravels (1.5" max). • Velocities > 5 ft/s and ≤ 8 ft/s*** *** Where there are increased velocities with <u>minor</u> bed load volumes ≤ 1.5" (e.g. storm drain systems or culverts ≤ 30" dia.), higher velocities may be applicable to level 3	All allowable pipe materials listed in Table 857.2 with the following considerations: • Steel pipe may need one of the abrasive resistant protective coatings listed in Table 855.2C or additional gauge thickness if existing pipes in the same vicinity have demonstrated susceptibility to abrasion and thickness for structural requirements is inadequate for abrasion potential. • Aluminum pipe may require additional gauge thickness for abrasion if thickness for structural requirements is inadequate for abrasion potential. • Aluminized steel (type 2) not recommended without invert protection or increased gauge thickness (equivalent to galv. Steel) where pH < 6.5 and resistivity < 20,000. Lining alternatives: • PVC, • Corrugated or Solid Wall HDPE, • CIPP

Table 855.2A
Abrasion Levels and Materials (Con't)

Level 4	• Small to moderate bed load volumes of sands, gravels, and/or small cobbles/rocks with maximum stone sizes up to about 6 in. • Velocities > 8 ft/s and ≤ 12 ft/s	All allowable pipe materials listed in Table 857.2 with the following considerations: • Steel pipe will typically need one of the abrasive resistant protective coatings listed in Table 855.2C or may need additional gauge thickness if thickness for structural requirements is inadequate for abrasion potential. • Aluminum pipe not recommended. • Aluminized steel (type 2) not recommended without invert protection or increased gauge thickness (wear rate equivalent to galv. steel) where pH < 6.5 and resistivity < 20,000 if thickness for structural requirements is inadequate for abrasion potential. • Increase concrete cover over reinforcing steel for RCB (invert only). RCP generally not recommended. • Corrugated HDPE (Type S) limited to ≥ 48" min. diameter. Corrugated HDPE Type C not recommended. • Corrugated and ribbed PVC limited to ≥ 18" min. diameter Lining alternatives: • Closed profile or SDR 35 PVC (corrugated and ribbed PVC limited to ≥ 18" min. diameter. Machine-wound PVC not recommended. • SDR HDPE (corrugated HDPE Type S and corrugated HDPE Type C not recommended). • CIPP (min. thickness for abrasion specified) • Concrete.

Table 855.2A
Abrasion Levels and Materials (Con't)

Level 5	• Moderate bed load volumes of sands, gravels, and/or small cobbles with maximum stone sizes up to about 6 in. For larger stone sizes within this velocity range, see Level 6 • Velocities > 12 ft/s and ≤ 15 ft/s	• Aluminum pipe not recommended. • Aluminized steel (type 2) not recommended without invert protection or increased gauge thickness (wear rate equivalent to galv. steel) where pH < 6.5 and resistivity < 20,000 if thickness for structural requirements is inadequate for abrasion potential. • Closed profile and SDR 35 PVC liners o but not recommended for upper range of stone sizes in bed load if freezing conditions are often encountered, otherwise allowed for stone sizes up to 3 in. • Most abrasive resistant coatings listed in Table 855.2C are not recommended for steel pipe. A concrete invert lining or additional gauge thickness is recommended if thickness for structural requirements is inadequate for abrasion potential. See lining alternatives below. • Increase concrete cover over reinforcing steel for RCB (invert only). RCP generally not recommended Lining alternatives: • Closed profile (≥ 42 in) or SDR 35 PVC (corrugated and ribbed not recommended. Machine-wound PVC not recommended) • SDR HDPE (corrugated Type S and Type C not recommended) • CIPP (with min. thickness for abrasion specified) • Concrete

Table 855.2A
Abrasion Levels and Materials (Con't)

Level 6	• Heavy bed load volumes of sands, gravel and rocks, with stone sizes 6 in or larger • Velocities > 12 ft/s and ≤ 20 ft/s or • Heavy bed load volumes of sands, gravel and small cobbles, with stone sizes up to about 6 in • Velocities > 15 ft/s and ≤ 20 ft/s**** ****Very limited data on abrasion resistance for velocities > 20 ft/s; contact District Hydraulics Branch.	• Aluminum pipe not recommended. • Aluminized steel (type 2) not recommended without invert protection or increased gauge thickness (wear rate equivalent to galv. steel) where pH < 6.5 and resistivity < 20,000. • None of the abrasive resistant protective coatings listed in Table 855.2C are recommended for protecting steel pipe. • A concrete invert lining and additional gauge thickness is recommended. See lining alternatives below. • Corrugated HDPE not recommended. Corrugated and closed profile PVC pipe not recommended. • RCP not recommended. Increase concrete cover over reinforcing steel recommended for RCB (invert only) for velocities up to 15 ft/s. RCB not recommended for bed load stone sizes > 3 in and velocities greater than 15 ft/s unless concrete lining with larger, harder aggregate is placed (see lining alternatives below). • SDR 35 PVC liners (≥ 27 in) allowed but not recommended for upper range of stone sizes in bed load if freezing conditions are often encountered, otherwise allowed for stone sizes up to 3 in. Lining/replacement alternatives: • SDR 35 PVC (see note above) or HDPE SDR (minimum wall thickness 2.5") • CIPP (with min. thickness for abrasion specified), • Class 2 concrete with embedded aggregate (e.g. cobbles or RSP (facing)): (for all bed load sizes a larger, harder aggregate than the bed load, decreased water cement ratio and an increased concrete compressive strength should be specified). • Alternative invert linings may include steel plate, rails or concreted RSP, and abrasion resistant concrete (Calcium Aluminate). • For new/replacement construction, consider "bottomless" structures.

Table 855.2B
Bed Materials Moved by Various Flow Depths and Velocities

Bed Material	Grain Dimensions (inches)	Approximate Nonscour Velocities (feet per second)			
		Mean Depth (feet)			
		1.3	3.3	6.6	9.8
Boulders	more than 10	15.1	16.7	19.0	20.3
Large cobbles	10 – 5	11.8	13.4	15.4	16.4
Small cobbles	5 – 2.5	7.5	8.9	10.2	11.2
Very coarse gravel	2.5 – 1.25	5.2	6.2	7.2	8.2
Coarse gravel	1.25 – 0.63	4.1	4.7	5.4	6.1
Medium gravel	0.63 – 0.31	3.3	3.7	4.1	4.6
Fine gravel	0.31 – 0.16	2.6	3.0	3.3	3.8
Very fine gravel	0.16 – 0.079	2.2	2.5	2.8	3.1
Very coarse sand	0.079 – 0.039	1.8	2.1	2.4	2.7
Coarse sand	0.039 – 0.020	1.5	1.8	2.1	2.3
Medium sand	0.020 – 0.010	1.2	1.5	1.8	2.0
Fine sand	0.010 – 0.005	0.98	1.3	1.6	1.8
Compact cohesive soils					
Heavy sandy loam		3.3	3.9	4.6	4.9
Light		3.1	3.9	4.6	4.9
Loess soils in the conditions of finished settlement		2.6	3.3	3.9	4.3

Notes:

(1) Bed materials may move if velocities are higher than the nonscour velocities.

(2) Mean depth is calculated by dividing the cross-sectional area of the waterway by the top width of the water surface. If the waterway can be subdivided into a main channel and an overbank area, the mean depths of the channel and the overbank should be calculated separately. For example, if the size of moving material in the main channel is desired, the mean depth of the main channel is calculated by dividing the cross-sectional area of the main channel by the top width of the main channel.

Table 855.2C

Guide for Anticipated Service Life Added to Steel Pipe by Abrasive Resistant Protective Coating

Flow Velocity (ft/s)	Channel Materials	Bituminous Coating (yrs.) (hot-dipped)	Bituminous Coating & Paved Invert (yrs.)	Polymerized Asphalt (yrs.) (hot-dipped)	Polymeric Sheet Coating (yrs.)	Polyethylene (CSSRP) (yrs.)
< 5 (1)	Non-Abrasive	8	15	*	*	*
$\geq 3 - \leq 8$ (2)	Abrasive	6-0	15-2	30-5	30-5	*
$> 8 - \leq 12$	Abrasive	0	2-0	5-0	5-0	70-35
$> 12 - \leq 15$	Abrasive	**	**	**	**	35-8***
$> 15 - \leq 20$ or $> 12 - \leq 20$	Abrasive & heavy bedloads	****	****	****	****	****

* Provides adequate abrasion resistance to meet or exceed a 50-year design service life.

** Abrasive resistant protective coatings not recommended, increase steel thickness to 10 gage.

*** Not recommended above 14 fps flow velocity.

**** Contact District Hydraulics Branch. See Table 855.2F.

Notes:

(1) Where there are increased velocities with no bedload (e.g. urban storm drain systems or culverts ≤ 30" dia.), higher velocities may be applicable.
(2) Where there are increased velocities with minor bedload (e.g. urban storm drain systems or culverts ≤ 30" dia.), higher velocities may be applicable.
(3) Range of additional service life commensurate with flow velocity range.

Table 855.2D

Guide for Anticipated Wear to Metal Pipe by Abrasive Channel Materials

Flow Velocity (ft/s)	Channel Materials	Anticipated Wear (mils/yr)		
		Plain Galvanized	Aluminized Steel (Type 2)	Aluminum**
	Non-Abrasive	0*	0*	0
≥ 3 – ≤ 8	Abrasive	0*	0*	0 – 1.5
> 8 – ≤ 12	Abrasive	0.5 – 1	0.5 – 1	1.5 – 3
> 12 – ≤ 15	Abrasive	1 – 3.5	1 – 3.5	3 – 10.5
> 15 – ≤ 20 or > 12 – ≤ 20	Abrasive & Heavy bedloads	2.5 – 10	2.5 – 10	7.5 – 30

* Refer to California Test 643 and Figure 855.3B.

** Refer to Figure 855.3A.

Note:

1 mil = 0.001"

Table 855.2E

Relative Abrasion Resistance Properties of Pipe and Lining Materials*

Material	Relative Wear (dimensionless)
Steel	1
Aluminum	1.5 – 3
PVC	2
Polyester Resin (CIPP)	2.5 – 4
HDPE	4 – 5
Concrete (RCP 4000 – 7000 psi)	75 – 100
Calcium Aluminate (Mortar)	6
Basalt Tile	1
Polyethylene (CSSRP)	1 – 2

* Evaluation of Abrasion Resistance of Pipe and Pipe Lining Materials Final Report FHWA/CA/TL-CA01-0173 (2007).

Table 855.2F

Guide for Minimum Material Thickness of Abrasive Resistant Invert Protection to Achieve 50 Years of Maintenance-Free Service Life

Abrasion Level & Flow Velocity (ft/s)	Channel Materials	Concrete (in)	Steel Pipe & Plate (in)	Aluminum Pipe & Plate (in)	PVC (in)	HDPE (in)	CIPP (in)	Calcium Aluminate Abrasion Resistant Concrete (in)
Level 4 > 8 – ≤ 12	Abrasive	2 – 4	N/A	0.075 – 0.164	0.1	0.125 – 0.25	0.1 – 0.3	N/A
Level 5 > 12 – ≤ 15	Abrasive	4 – 13	0.052 – 0.18	**	0.1 – 0.35	0.25 – 0.875	0.3 – 0.70	N/A
Level 6 > 15 – ≤ 20 or > 12 – ≤ 20	Abrasive & Heavy bedloads	*	0.28 – 0.5 or 0.109 – 0.5	**	0.55 – 1.0*** or 0.25 – 1.0***	1.25 – 2.5 or 0.625 – 2.5	1 – 2 or 0.5 – 2	3 – 4

* For flow velocity > 12 ft/s ≤ 14 ft/s use 9" – 15". For > 14 ft/s use CRSP or other abrasion resistant layer special design with, or in lieu of concrete.

** Not recommended without invert protection.

*** Limited to 3" maximum stone size, otherwise PVC not recommended.

855.3 Corrosion

Corrosion is the destructive attack on a pipe by a chemical reaction with the materials surrounding the pipe. Corrosion problems can occur when metal pipes are used in locations where the surrounding materials have excess acidity or alkalinity. The relative acidity of a substance is often expressed by its pH value. The pH scale ranges from 1 to 14, with 1 representing extreme acidity, and 14 representing extreme alkalinity, and 7 representing a neutral substance. The closer the pH value is to 7, the less potential the substance has for causing corrosion.

Corrosion is an electrolytic process and requires an electrolyte (generally moisture) and oxygen to proceed. As a result, it has the greatest potential for causing damage in soils that have a relative high ability to pass electric current. The ability of a soil to convey current is expressed as its resistivity in ohm-cm, and a soil with a low resistivity has a greater ability to conduct electricity. Very dry areas (e.g., desert environments) have a limited availability of electrolyte, and totally and continuously submerged pipes have limited oxygen availability. These extreme conditions (among others) are not well represented by AltPipe, and some adjustment in the estimated service life for pipes in these conditions should be made. See Index 857.2

Corrosion can also be caused by excessive acidity in the water conveyed by the pipe. Water pH can vary considerably between watersheds and seasons.

Because failure can occur at any point along the length of the pipe (e.g. tidal zones), the designer must look at the conditions and how they may vary along the pipe length - and select for input into AltPipe those conditions that represent the most severe situation along the length.

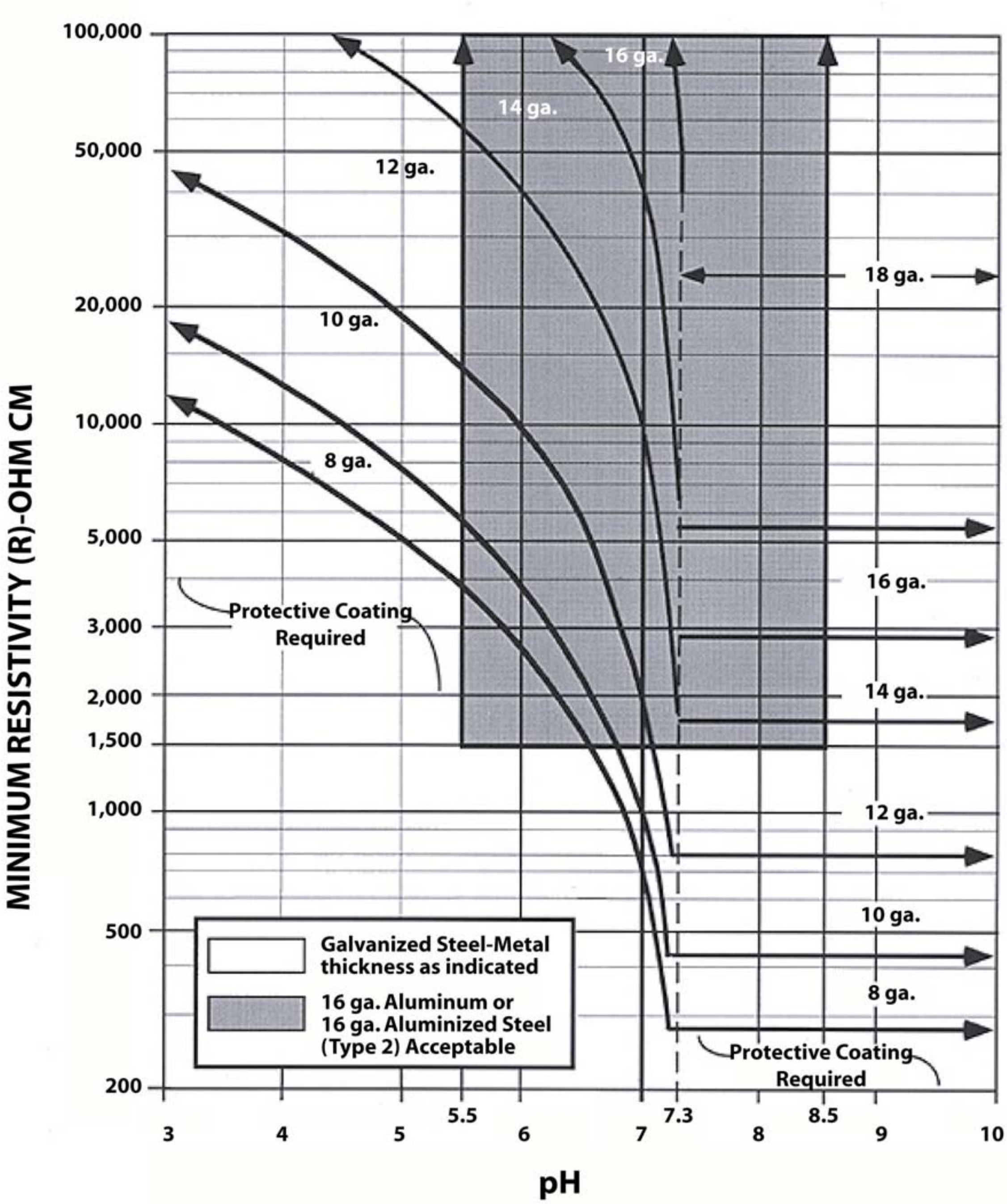
AltPipe operates based on some fairly basic assumptions for corrosion and minimum resistivity that are part of California Test 643. Altpipe will list all viable alternatives for achieving design service life. Where enhanced soilside corrosion protection is needed, aluminum or aluminized pipe (if within acceptable pH/min. resistivity ranges), bituminous coatings or polymeric sheet coating should be considered.

Aluminum, and the aluminum coating provided by Aluminized Steel (Type 2) pipe, corrodes differently than steel and will provide adequate durability to meet the 50-year service life criterion within the acceptable pH range of 5.5-8.5 and minimum resistivity greater than 1500 ohm-cm without need for specifying a thicker gauge or additional coating, whereas under the same range galvanized steel may need a protective coating or an increase in thickness to provide a 50-year maintenance-free service life (with respect to corrosion). Figure 855.3A should be used to determine the limitations on the use of corrugated aluminum pipe for various levels of pH and minimum resistivity. The minimum thickness (0.060 inch) of aluminum pipe obtained from the chart only satisfies corrosion requirements. Overfill requirements for minimum metal thickness must also be satisfied. The metal thickness of corrugated aluminum pipe should satisfy both requirements.

Figure 855.3A should be used to determine the minimum thickness and limitation on the use of corrugated steel and spiral rib pipe for various levels of pH and minimum resistivity. For example, given a soil environment with pH and minimum resistivity levels of 6.5 and 15,000 ohm-cm, respectively, the minimum thicknesses for the various metal pipes are: 1) 0.109 inch (12 gage) galvanized steel, 2) 0.064 inch (16 gage) aluminized steel (type 2) and 3) 0.060 inch (16 gage) aluminum. The minimum thickness of metal pipe obtained from the figure only satisfies corrosion requirements. Overfill requirements for minimum metal thickness must also be satisfied. The metal thickness of corrugated pipe and steel spiral rib pipe that satisfies both requirements should be used.

Figure 855.3B, "Chart for Estimating Years to Perforation of Steel Culverts," is part of a Standard California Department of Transportation Test Method derived from highway culvert investigations. This chart alone is not used for determining service life because it does not consider the effects of abrasion or overfill; it is for estimating the years to the first corrosion perforation of the wall or invert of the CSP.

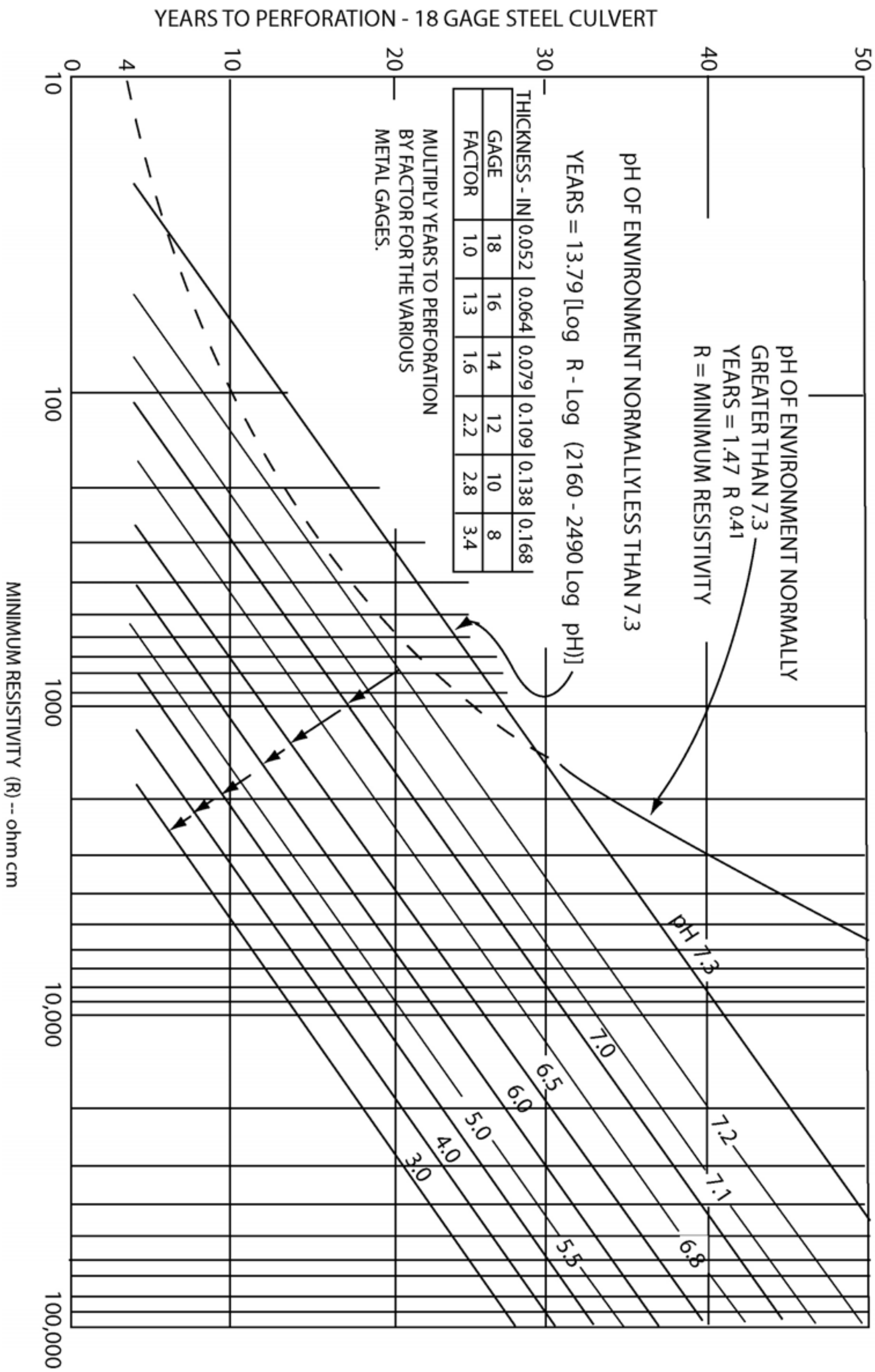
Figure 855.3A
Minimum Thickness of Metal Pipe
for 50 Year Maintenance-Free Service Life (2)



Notes:
1. For pH and minimum resistivity levels not shown refer to Fig. 854.3C steel pipes. (California Test 643)
2. Service life estimate are for various corrosive conditions only.
3. Refer to index 854.3(2) and 854.4(2) for appropriate selection of metal thickness and protection coating to achieve service life requirements.

Figure 855.3B

Chart for Estimating Years to Perforation of Steel Culverts



THICKNESS - IN	0.052	0.064	0.079	0.109	0.138	0.168
GAGE	18	16	14	12	10	8
FACTOR	1.0	1.3	1.6	2.2	2.8	3.4

855.4 Protection of Concrete Pipe and Drainage Structures from Acids, Chlorides and Sulfates

Table 855.4A indicates the limitation on the use of concrete by acidity of soil and water. Table 855.4A is also a guide for designating cementitious material restrictions and water content restrictions for various ranges of sulfate concentrations in soil and water for all cast in place and precast construction of drainage structures.

For pH ranging between 7.0 and 3.0 and for sulfate concentrations between 1500 and 15,000 ppm, concrete mix designs conforming to the recommendations given in Table 855.4A should be followed. Higher sulfate concentrations or lower pH values may preclude the use of concrete or would require the designer to develop and specify the application of a complete physical barrier. Reinforcing steel can be expected to respond to corrosive environments similarly to the steel in CSP.

Table 855.4B provides a guide for minimum concrete cover requirements for various ranges of chloride concentrations in soil and water for all precast and cast in place construction of drainage structures.

(1) *RCP*. In relatively severe acidic, chloride or sulfate environments (either in the soil or water) as identified in the project Materials Report, the means for offsetting the effects of the corrosive elements is to either increase the cover over the reinforcing steel, increase the cementitious material content, or reduce the water/ cementitious material ratio. The identified constituent concentration levels should be entered into AltPipe to verify what combinations of increased cover (in 1/4-inch intervals from 1 inch to a maximum of 1-1/2 inches), increased cementitious material content (in increments of 47 pounds from 470 pounds to a maximum of 564 pounds), will provide the necessary service life (typically 50 years). Per an agreement with Industry, the water to cementitious material ratio is set at 0.40. AltPipe is specifically programmed to provide RCP mix and cover designs that are compatible with industry practice, and are based on their agreements with Caltrans. For corrosive condition installations such as low pH (<4.5), Chlorides (>2,000 ppm) or Sulfates (> 2,000 ppm), the following service life (SL) equation provides the basis for RCP design in AltPipe:

$$SL = 10^3 \times 1.107^{Cc} \times Cc^{0.717} \times Dc^{1.22} \times (K+1)^{-0.37} \times W^{-0.631} - 4.22 \times 10^{10} \times pH^{-14.1} - 2.94 \times 10^{-3} \times S + 4.41$$

Where: S = Environmental sulfate content in ppm.

Cc = Sacks of cement (94 lbs each) per cubic yard of concrete.

Dc = Concrete cover in inches.

K = Environmental chloride concentration in ppm.

W = Water by volume as percentage of total mix.

pH = The measure of relative acidity or alkalinity of the soil or water. See Index 855.3.

Where the measured concentration of chlorides exceeds 2000 ppm for RCP that is placed in brackish or marine environments and where the high tide line is below the crown of the invert, the AltPipe input for chloride concentration will default to 25,000 ppm.

Contact the District Materials unit or the Corrosion Technology Branch in DES for design recommendations when in extremely corrosive conditions. Non-Reinforced concrete pipe is not affected by chlorides or stray currents and may be used in lieu of RCP with additional concrete cover and/or protective coatings for sizes 36" in diameter and smaller. See Index 852.1(4) and Table 855.4A. Where conditions occur that RCP designs as produced by AltPipe will not work, the Office of State Highway Drainage Design within the Division of Design should be contacted.

Table 855.4A

Guide for the Protection of Cast-In-Place and Precast Reinforced and Unreinforced Concrete Structures(5) Against Acid and Sulfate Exposure Conditions(1),(2)

Soil or Water pH	Sulfate Concentration of Soil or Water (ppm)	Cementitious Material Requirements (3)	Water Content Restrictions
7.1 to 14	0 to 1,500	Standard Specifications Section 90-2.01C	No Restrictions
5.6 to 7.0	Greater Than 1,500 to 2,000	Standard Specifications Section 90-2.01C	Maximum water-to-cementitious material ratio of 0.45
3 to 5.5(4)	Greater Than 2,000 to 15,000(4)	675 lb/cy minimum: Type II or Type V portland cement and required supplementary cementitious materials per Specification S8-C04	Maximum water-to-cementitious material ratio of 0.40

Notes:

(1) Recommendations shown in the table for the cementitious material requirements and water content restrictions should be used if the pH and/or the sulfate conditions in Column 1 and/or Column 2 exists. Sulfate testing is not required if the minimum resistivity is greater than 1,000 ohm-cm.

(2) The table lists soil/water pH and sulfate concentration in increasing level of severity starting from the top of the table. If the soil/water pH and the sulfate concentration are at different levels of severity, the recommendation for the more severe level will apply. For example, a soil with a pH of 4.0, but with a sulfate concentration of only 1,600 ppm would require a minimum of 675 lb/cy of cementitious material. The cementitious material would consist of 75% by weight Type II or Type V cement plus 25% by weight supplementary cementitious material admixture. The maximum water-to-cementitious material ratio would be 0.40.

(3) Cementitious material shall conform to the provisions in Section 90-2, "Materials," of the Standard Specifications. Fly ash or natural pozzolan may have a CaO content of up to 10%.

(4) Additional mitigation measures will be needed for conditions where the pH is less than 3 and/or the sulfate concentration exceeds 15,000 ppm. Mitigation measures may include additional concrete cover and/or protective coatings. For additional assistance, contact the Corrosion Technology Branch or the Office of Rigid Pavement Materials and Structural Concrete of the Division of Materials Engineering and Testing Services (METS) at 5900 Folsom Boulevard Sacramento, CA. 95819.

(5) Does not include RCP.

Table 855.4B

Guide for Minimum Cover Requirements for Cast-In-Place and Precast Reinforced Concrete Structures(3) for 50-Year Design Life in Chloride Environments

Chloride Concentration (ppm)			
500 to 2000	2001 to 5000	5001 to 10000	10000 +
1.5 in.(1)	2.5 in.(1)	3 in.(1)	4 in.(1)
1.5 in.(2)	1.5 in.(2)	2 in.(2)	3 in.(2)

Notes:

(1) Supplementary cementitious materials are required. Typical minimum requirement consists of 675#/cy minimum cementitious material with 75% by weight of Type II or Type V portland cement and 25% by weight of either fly ash or natural pozzolan. A maximum w/cm ratio of 0.40 is specified. Fly ash or natural pozzolan may have a CaO content of up to 10%. Specification S8-C04 provides requirements.

(2) Additional supplementary cementitious materials per the requirements of Specification S8-C04 are required in order to achieve the listed reduction in concrete cover.

(3) Does not include RCP.

855.5 Material Susceptibility to Fire

Fire can occur almost anywhere on the highway system. Common causes include forest, brush or grass fires that either enter the right-of-way or may begin within it. Less common causes include spills of flammable liquids that ignite. Storm drains, which are completely buried, are only potentially problematic from spills because these are such low probability events. Therefore, prohibitions on material placement for storm drains are not warranted.

Limitations for any material type may be considered for cross culverts and exposed overside drains that may be subject to burning or melting with the understanding that end treatments will often provide some level of protection.

Because the probability of a fire is relatively low, it is acceptable to use pipe materials that are susceptible to fire damage in most locations. In some locations, however, there is a greater chance of fire. Examples include highways alongside fields and ditches that are routinely burned for clearing, and pipes in areas where flammable liquids are stored or processed, such as fuel yards or refineries. Plastic pipe or pipe coatings that are susceptible to fire damage should generally be avoided in these higher risk areas. Pipe coatings that are susceptible to fire damage include bituminous or plastic coated pipes because the coating can melt and burn. Plastic pipe is flammable; PVC will melt and burn under high temperatures but is inherently difficult to ignite and will self-extinguish once the heat source is removed. HDPE will continue to burn as long as adequate oxygen supply is present. Based on testing performed by Florida DOT, this rate of burning is fairly slow, and often “burned itself out” if there wasn't sufficient airflow through the pipe. End treatments using concrete end or headwalls will limit the possibility of fire damage and are recommended where plastic pipe or pipe coatings that are susceptible to fire damage are to be placed where there is a greater chance of fire. In areas with high fire potential, use limitations or modifications of plastic pipe should be considered. Application limitations may include down drains and projecting ends of cross drains in densely vegetated or grassy locations. The projecting ends of plastic pipe cross drains can be replaced with corrugated metal pipe, concrete pipe, concrete headwalls or wingwalls, or other modifications, thereby reducing the potential of fire damage. The connection between the plastic pipe and the modified end piece would be nonstandard.

Topic 856 - Height of Fill

An essential aspect of pipe selection is the height of fill/cover over the pipe. This cover dissipates live loads from traffic, both during construction and after the facility is open to the public.

856.1 Construction Loads

See Standard Plan D88 for table of minimum cover for construction loads.

856.2 Concrete Pipe, Box and Arch Culverts

(1) *Reinforced Concrete Pipe.* See Standard Plan A62D and A62DA for the maximum height of overfill for reinforced concrete pipe, up to and including 108-inch diameter (or reinforced oval pipe and reinforced concrete pipe arch with equivalent cross-sectional area), using the backfill method specified in Standard Specification Section 19-3.06, Structure Backfill. For oval shaped reinforced concrete pipe fill heights, see Standard Plan A62D and Indirect Design D-Load (Marsten/Spangler Method). Allowable cover for oval shaped reinforced concrete pipe is determined by using Method 2 (Note 8). See Standard Plan D79 for pre-cast reinforced concrete pipe Direct Design Method (pertains to circular pipe only).

The designer should be aware of the premises on which the tables on Standard Plan A62D and A62DA are computed as well as their limitations. The cover presupposes:

- That the bedding and backfill satisfy the terms of the Standard Specifications, the conditions of cover and pipe size required by the plans, and take into account the essentials of Index 829.2.
- That a small amount of settlement will occur under the culvert equal in magnitude to that of the adjoining material outside the trench.

- Subexcavation and backfill as required by the Standard Specifications where unyielding foundation material is encountered.

If the height of overfill exceeds the tabular values on Standard Plan A62D and A62DA a special design is required; see Index 829.2.

(2) *Cast In Place Non Reinforced Concrete Pipe.* The maximum allowable height of cover for cast-in-place concrete pipe is given in Table 856.2. The designer should review Standard Plan A62-D for additional installation criteria.

(3) *Concrete Box and Arch Culverts.* Single and multiple span reinforced concrete box culverts are completely detailed in the Standard Plans. For cast-in-place construction, strength classifications are shown for 10 feet and 20 feet overfills. See Standard Plan numbers D80, D81 and D82. Pre-cast reinforced concrete box culverts require a minimum of 1 foot overfill and limit fill height to 12 feet maximum. See XS-Sheets xs17-020e, 030e and 040e. For fill height design criteria for CIP Bottomless 3-sided rigid frame culverts see XS-Sheets xs17-050-1e, 2e, 3e and 4e. Cast-in-place reinforced concrete arch culverts are no longer economically feasible structures and last appeared in the 1997 Standard Plans. Questions regarding fill height for concrete arch culverts or extensions should be directed to the Underground Structures Branch of DES - Structures Design.

Table 856.2 Cast-in-Place Concrete Pipe Fill Height Table

Diameter (in)	Concrete Strength (psi)			
	3,500	4,000	4,500	5,000
	Maximum Fill Height (ft)			
30	13	13	14	15
36	12	13	14	15
42	11	12	13	14
48	13	14	15	16
54	13	14	15	16
60	12	13	14	15
66	12	13	14	15
72	11	12	13	14
78	11	12	13	14
84	11	12	13	14

Note:
(1) For non-reinforced precast concrete pipe, refer to Index 852.1(4) and Standard Plan A62D, Note 7.

856.3 Metal Pipe and Structural Plate Pipe

Basic Premise - To properly use the fill height design tables, the designer should be aware of the premises on which the tables are based as well as their limitations. The design tables presuppose:

- That bedding and backfill satisfy the terms of the Standard Specifications and Standard Plan A62F, the conditions of cover, and pipe size required by the plans and the essentials of Index 829.2.
- That a small amount of settlement will occur under the culvert, equal in magnitude to that of the adjoining material outside the trench.

Limitations - In using the tables, the following restrictions must be kept in mind:

- The values given for each size of pipe constitute the maximum height of overfill or cover over the pipe for the thickness of metal and kind of corrugation.
- The thickness shown is the structural minimum. Where abrasive conditions are anticipated, additional metal thickness or invert treatments

as stated under Index 852.4(5) and Index 852.6(2)(c) should be provided when required to fulfill the design service life requirements of Topic 855.

- Where needed, adequate provisions for corrosion resistance must be made to achieve the required design service life called for in the references mentioned herein.
- Table 856.3D shows the limit of heights of cover for corrugated steel pipe arches based on the supporting soil sustaining a bearing pressure varying between 2½ tons per square feet to 4¼ tons per square feet. Table 856.3J shows similar values for corrugated aluminum pipe arches.
- The values given for each size of structural plate pipe or arch constitute the maximum height of overfill or cover over the pipe or arch for the thickness of metal and kind of corrugation.
- Tables 856.3N & P show the limit of heights of cover for structural plate arches based on the supporting soil sustaining a bearing pressure of 3 tons per square foot at the corners.

Special Designs.

- If the height of overfill exceeds the tabular values, or if the foundation investigation reveals that the supporting soil will not develop the bearing pressure on which the overfill heights for pipe arches are based, a special design prepared by DES - Structures Design is required. See index 829.2.
- Non-standard pipe diameters and arch sizes are available. Loading capacity of special designs needs to be verified with the Underground Structures Branch of DES - Structures Design.

(1) *Corrugated Steel Pipe and Pipe Arches, Steel Spiral Rib Pipe, Structural Steel Plate Pipe and Structural Steel Plate Pipe Arches.* The allowable overfill heights for corrugated steel pipe and pipe arches for the various diameters or arch sizes and metal thickness are shown on Tables 856.3A, B, C & D. For steel spiral rib pipe, overfill heights are shown on Tables 856.3E, F, G & H. Table 856.3G gives the allowable overfill height for composite steel spiral rib pipe.

For structural steel plate pipe and structural steel plate pipe arches, overfill heights are shown on Tables 856.3M & N. For maximum height of fill over structural steel plate vehicular undercrossings, see Standard Plan B14-1.

(2) *Corrugated Aluminum Pipe and Pipe Arches, Aluminum Spiral Rib Pipe and Structural Aluminum Plate Pipe and Structural Aluminum Plate Pipe Arches.* The allowable overfill heights for corrugated aluminum pipe and pipe arches for various diameters and metal thickness are shown on Tables 856.3H, I & J. For aluminum spiral rib pipe, overfill heights are shown on Tables 856.3K & L.

For structural aluminum plate pipe and structural aluminum plate pipe arches, overfill heights are shown on Tables 856.3O, & P.

Table 856.3A

Corrugated Steel Pipe Helical Corrugations

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)					
	Metal Thickness (in)					
	0.052 (18 ga.)	0.064 (16 ga.)	0.079 (14 ga.)	0.109 (12 ga.)	0.138 (10 ga.)	0.168 (8 ga.)
	2⅔" x ½" Corrugations					
12-15	99	99	--	--	--	--
18	89	99	--	--	--	--
21	77	96	99	--	--	--
24	67	84	99	--	--	--
30	53	67	84	99	--	--
36	44	56	70	98	99	--
42	38	48	60	84	99	--
48	--	42	52	79	94	99
54	--	--	46	65	84	92
60	--	--	--	59	75	92
66	--	--	--	--	69	84
72	--	--	--	--	63	77
78	--	--	--	--	--	68
84	--	--	--	--	--	59
	3" x 1" Corrugations					
48	--	48	60	84	108	133
45	--	43	53	75	97	118
60	--	38	48	67	87	105
66	--	35	44	61	79	97
72	--	32	40	56	72	89
78	--	29	37	52	67	82
84	--	27	34	48	62	75
90	--	25	32	45	57	70
96	--	--	30	42	54	65
102	--	--	28	39	51	62
108	--	--	--	37	48	59
114	--	--	--	35	46	56
120	--	--	--	33	42	53

NOTE:

(1) When flow velocity exceeds 5 ft/s under abrasive conditions, thicker metal may be required.

Table 856.3B

Corrugated Steel Pipe
Helical Corrugations

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)			
	Metal Thickness (in)			
	0.064 (16 ga.)	0.079 (14 ga.)	0.109 (12 ga.)	0.138 (10 ga.)
	5" x 1" Corrugations			
48	43	54	75	--
54	38	48	67	86
60	34	43	60	77
66	31	39	55	70
72	28	36	50	64
78	26	33	46	59
84	24	30	43	55
90	23	28	40	51
96	--	27	37	48
102	--	25	35	45
108	--	--	33	43
114	--	--	31	40
120	--	--	30	38

NOTE:
(1) When flow velocity exceeds 5 ft/s under abrasive conditions, thicker metal may be required.

Table 856.3C

Corrugated Steel Pipe
2⅔" x ½" Annular Corrugations

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)				
	Metal Thickness (in)				
	0.064 (16 ga.)	0.079 (14 ga.)	0.109 (12 ga.)	0.138 (10 ga.)	0.168 (8 ga.)
18	54	--	--	--	--
21	47	--	--	--	--
24	41	44	--	--	--
30	32	35	--	--	--
36	27	29	38	--	--
42	30	40	62	68	--
48	26	36	54	60	63
54	--	32	48	53	50
60	--	--	43	48	50
66	--	--	--	43	45
72	--	--	--	40	42
78	--	--	--	--	38
84	--	--	--	--	36

NOTE:
(1) When flow velocity exceeds 5 ft/s under abrasive conditions, thicker metal may be required.

Table 856.3D

Corrugated Steel Pipe Arches
2⅔" x ½" Helical or Annular Corrugations

			MAXIMUM HEIGHT OF COVER (ft)			
			Metal Thickness (in)			
Span-Rise (in)	Design Bearing (tons/ft^2)	Minimum Corner Radius (in)	0.079 (14 ga.)	0.109 (12 ga.)	0.138 (10 ga.)	0.168 (8 ga.)
21 x 15	2½	3.0	10	--	--	--
24 x 18	2¾	3.0	10	--	--	--
28 x 20	3¼	3.0	10	--	--	--
35 x 24	4¼	3.0	10	--	--	--
42 x 29	4¼	3.5	10	--	--	--
49 x 33	4¼	4.0	10	--	--	--
57 x 38	4	5.0	--	10	--	--
64 x 43	3¾	6.0	--	10	--	--
71 x 47	3½	7.0	--	--	10	--
77 x 52	3½	8.0	--	--	--	10
83 x 57	3¼	9.0	--	--	--	10

NOTES:
(1) When flow velocity exceeds 5 ft/s under abrasive conditions, thicker metal may be required.
(2) Cover limited by corner soil bearing pressure as shown.

Table 856.3E

Steel Spiral Rib Pipe
¾" x 1" Ribs at 11½" Pitch

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)		
	Metal Thickness (in)		
	0.064 (16 ga.)	0.079 (14 ga.)	0.109 (12 ga.)
24	40	57	96
30	32	45	76
36	27	38	64
42	23	32	54
48	20	28	48
54	18	25	42
60	16	22	38
66	--	20	34
72	--	19	32
78	--	--	29
84	--	--	27
90	--	--	25
96	--	--	24

NOTE:
(1) When flow velocity exceeds 5 ft/s under abrasive conditions, thicker metal may be required.

Table 856.3F

Steel Spiral Rib Pipe
¾" x 1" Ribs at 8½" Pitch

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)		
	Metal Thickness (in)		
	0.064 (16 ga.)	0.079 (14 ga.)	0.109 (12 ga.)
24	54	75	125
30	43	60	100
36	36	50	83
42	31	43	71
48	27	37	62
54	24	33	55
60	21	30	50
66	19	27	45
72	18	25	41
78	--	23	38
84	--	21	35
90	--	--	33
96	--	--	31
102	--	--	29
108	--	--	27
114	--	--	26

NOTE:

(1) When flow velocity exceeds 5 ft/s under abrasive conditions, thicker metal may be required.

Table 856.3G

Steel Spiral Rib Pipe
¾” x ¾" Ribs at 7½" Pitch

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)		
	Metal Thickness (in)		
	0.064 (16 ga.)	0.079 (14 ga.)	0.109 (12 ga.)
24	55	77	128
30	44	62	103
36	36	51	85
42	31	44	73
48	27	38	64
54	24	34	57
60	--	31	51
66	--	28	46
72	--	--	42
78	--	--	39
84	--	--	36

NOTE:
(1) When flow velocity exceeds 5 ft/s under abrasive conditions, thicker metal may be required.

Table 856.3H
Corrugated Aluminum Pipe
Annular Corrugations

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)				
	Metal Thickness (in)				
	0.060 (16 ga.)	0.075 (14 ga.)	0.105 (12 ga.)	0.135 (10 ga.)	0.164 (8 ga.)
	2⅔" x ½" Corrugations				
12	44	44	--	--	--
15	35	35	61	--	--
18	29	29	51	--	--
21	25	25	43	--	--
24	22	22	38	39	--
30	--	17	30	31	--
36	--	14	25	26	--
42	--	--	44	46	--
48	--	--	38	40	41
54	--	--	--	36	37
60	--	--	--	32	33
66	--	--	--	--	30
72	--	--	--	--	26
	3" x 1" Corrugations				
30	32	40	55	82	--
36	27	33	45	68	89
42	23	28	39	59	76
48	20	25	34	51	66
54	18	22	30	45	59
60	16	20	27	41	53
66	14	18	25	37	48
72	13	16	22	34	44
78	--	15	21	31	41
84	--	--	19	29	38
90	--	--	18	27	35
96	--	--	17	25	33
102	--	--	--	24	31
108	--	--	--	22	29
114	--	--	--	--	26
120	--	--	--	--	23

NOTE:
(1) Not recommended under abrasive conditions.

Table 856.3I
Corrugated Aluminum Pipe
Helical Corrugations

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)				
	Metal Thickness (in)				
	0.060 (16 ga.)	0.075 (14 ga.)	0.105 (12 ga.)	0.135 (10 ga.)	0.164 (8 ga.)
	2⅔" x ½" Corrugations				
12	98	98	--	--	--
15	98	98	98	--	--
18	80	98	98	--	--
21	71	87	98	--	--
24	61	78	98	98	--
30	--	61	85	98	--
36	--	51	71	92	--
42	--	--	61	79	--
48	--	--	52	67	84
54	--	--	--	56	69
60	--	--	--	44	56
66	--	--	--	--	44
72	--	--	--	--	36
	3" x 1" Corrugations				
30	53	70	98	99	--
36	46	59	82	99	99
42	40	50	70	94	99
48	35	44	61	82	97
54	31	39	54	73	86
60	28	35	49	66	77
66	25	32	44	60	70
72	23	29	41	55	64
78	--	27	38	50	59
84	--	--	35	47	55
90	--	--	32	44	51
96	--	--	30	40	48
102	--	--	--	36	43
108	--	--	--	33	39
114	--	--	--	--	35
120	--	--	--	--	31

NOTE:
(1) Not recommended under abrasive conditions.

Table 856.3J

Corrugated Aluminum Pipe Arches
2⅔" x ½" Helical or Annular Corrugations

Span-Rise (in)	Req'd Bearing (tons/ft^2)	Minimum Corner Radius (in)	MAXIMUM HEIGHT OF COVER (ft) Metal Thickness (in) 0.060 (16 ga.)	0.075 (14 ga.)	0.105 (12 ga.)	0.135 (10 ga.)	0.164 (8 ga.)
17 x 13	2	3.0	10	--	--	--	--
21 x 15	2½	3.0	10	--	--	--	--
24 x 18	2¾	3.0	10	--	--	--	--
28 x 20	3¼	3.0	10	--	--	--	--
35 x 24	4	3.0		10	--	--	--
42 x 29	4¼	3.5	--	10	--	--	--
49 x 33	4¼	4.0	--	--	10	--	--
57 x 38	4	5.0	--	--	--	10	--
64 x 43	3¾	6.0	--	--	--	10	--
72 x 47	3½	7.0	--	--	--	--	10

NOTES:
(1) Cover is limited by corner soil bearing pressure as shown.
(2) Not recommended under abrasive conditions.

Table 856.3K

Aluminum Spiral Rib Pipe
¾" x 1” Ribs at 11½" Pitch

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)		
	Metal Thickness (in)		
	0.060 (16 ga.)	0.075 (14 ga.)	0.105 (12 ga.)
24	24	33	55
30	19	27	44
36	16	22	36
42	--	19	31
48	--	--	27
54	--	--	24
60	--	--	22
66	--	--	--
72	--	--	--

NOTE:
(1) Not recommended under abrasive conditions.

Table 856.3L

Aluminum Spiral Rib Pipe
¾" x ¾" Ribs at 7½" Pitch

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)		
	Metal Thickness (in)		
	0.60 (16 ga.)	0.075 (14 ga.)	0.105 (12 ga.)
24	32	45	72
30	26	36	57
36	21	30	48
42	--	25	42
48	--	--	36
54	--	--	32
60	--	--	28
66	--	--	--
72	--	--	--

NOTE:
(1) Not recommended under abrasive conditions.

Table 856.3M
Structural Steel Plate Pipe
6" x 2" Corrugations

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)					
	Metal Thickness (in)					
	0.109 (12 ga.)	0.138 (10 ga.)	0.168 (8 ga.)	0.218 (5 ga.)	0.249 (3 ga.)	0.280 (1 ga.)
60	55	81	105	137	159	178
66	50	74	96	125	145	162
72	46	68	88	114	133	149
77	42	62	81	106	122	137
84	39	58	76	99	113	127
90	36	54	71	92	105	119
96	35	51	66	87	99	112
102	32	48	62	81	93	105
108	30	45	59	77	88	99
114	29	43	56	73	83	94
120	27	40	53	69	79	89
126	26	38	50	66	75	85
132	25	37	48	63	72	81
138	24	35	46	60	69	77
144	23	34	44	58	66	74
150	22	32	42	55	63	71
156	21	31	40	53	61	68
162	20	30	39	51	58	66
168	19	29	38	49	56	64
174	19	28	36	48	54	61
180	18	27	35	46	52	59
186	17	26	34	44	51	57
192	--	25	33	43	49	56
198	--	24	32	42	48	54
204	--	24	31	40	46	52
210	--	23	30	39	45	51
216	--	--	29	38	44	49
222	--	--	28	37	42	48
228	--	--	28	36	41	47
234	--	--	27	35	40	45
240	--	--	--	34	39	44
246	--	--	--	33	38	43
252	--	--	--	33	37	42

NOTE:
(1) When flow velocities exceeds 5 ft/s under abrasive conditions thicker metal may be required.

Table 856.3N

Structural Steel Plate Pipe Arches
6" x 2" Corrugations

MAXIMUM HEIGHT OF COVER (ft)			
Span	Rise	Corner Soil Bearing – 3 tons/ft^2	
		Metal Thickness (in)	
		0.109 (12 ga.)	0.138 (10 ga.)
		18" Corner Radius	
6'-1"	4'-7"	21	--
7'-0"	5'-1"	18	--
7'-11"	5'-7"	16	--
8'-10"	6'-1"	14	--
9'-9"	6'-7"	13	--
10'-11"	7'-1"	11	--
		31" Corner Radius	
13'-3"	9'-4"	16	--
14'-2"	9'-10"	15	--
15'-4"	10'-4"	14	--
16'-3"	10'-10"	13	--
17'-2"	11'-4"	12	--
18'-1"	11'-10"	11	--
19'-3"	12'-4"	11	--
19'-11"	12'-10"	--	10
20'-7"	13'-2"	--	10

NOTES:
(1) For intermediate sizes, the depth of cover may be interpolated.
(2) The 31-inch corner radius arch should be specified when conditions will permit it use.

Table 856.3O

Structural Aluminum Plate Pipe
9" x 2½" Corrugations

Diameter (in)	MAXIMUM HEIGHT OF COVER (ft)						
	Metal Thickness (in)						
	0.100	0.125	0.150	0.175	0.200	0.225	0.250
60	36	54	66	77	88	99	99
66	33	49	60	70	80	90	99
72	30	45	55	64	73	83	92
78	28	41	51	59	68	76	85
84	26	38	47	55	63	71	79
90	24	36	44	51	59	66	74
96	23	33	41	48	55	62	69
102	21	31	39	45	52	58	65
108	20	30	37	43	49	55	61
114	19	28	35	40	46	52	58
120	18	27	33	38	44	49	55
126	17	25	31	36	42	47	52
132	16	24	30	35	40	45	50
138	16	23	28	33	38	43	48
144	15	22	27	32	36	41	46
150	--	21	26	31	35	39	44
156	--	20	25	29	34	38	42
162	--	--	24	28	32	36	41
168	--	--	23	27	31	35	39
174	--	--	22	26	30	34	38
180	--	--	--	25	29	33	37
186	--	--	--	25	28	32	35
192	--	--	--	--	27	31	34
198	--	--	--	--	26	30	33
204	--	--	--	--	26	29	32
210	--	--	--	--	--	28	31
216	--	--	--	--	--	27	30
222	--	--	--	--	--	--	30
228	--	--	--	--	--	--	29

NOTE:
(1) Not recommended under abrasive conditions.

Table 856.3P

Structural Aluminum Plate Pipe Arches
9" x 2½" Corrugations

		MAXIMUM HEIGHT OF COVER (ft)					
		Corner Soil Bearing – 3 tons/ft^2					
		Metal Thickness (in)					
Span	Rise	0.100	0.125	0.150	0.175	0.200	0.225
6'-7"	5'-8"	28	--	--	--	--	--
7'-9"	6'-0"	23	--	--	--	--	--
8'-10"	6'-4"	20	--	--	--	--	--
9'-11"	6'-8"	18	--	--	--	--	--
10'-3"	6'-9"	16	21	--	--	--	--
11'-1"	7'-0"	16	20	20	--	--	--
12'-3"	7'-3"	15	18	18	--	--	--
12'-11"	7'-6"	14	17	17	--	--	--
13'-1"	8'-2"	14	17	17	--	--	--
13'-11"	8'-5"	12	16	16	--	--	--
14'-0"	8'-7"	12	15	16	--	--	--
14'-8"	9'-8"	--	15	15	--	--	--
15'-7"	10'-2"	--	14	14	--	--	--
16'-1"	10'-4"	--	13	13	--	--	--
16'-9"	10'-8"	--	--	13	--	--	--
17'-9"	11'-2"	--	--	--	12	--	--
18'-8"	11'-8"	--	--	--	11	--	--
19'-10"	12'-1"	--	--	--	--	10	--
20'-10"	12'-7"	--	--	--	--	--	10
21'-6"	12'-11"	--	--	--	--	--	10

NOTES:
(1) Not recommended under abrasive conditions.
(2) 31 inch Corner Raduis

856.4 Plastic Pipe

The allowable overfill heights for plastic pipe for various diameters are shown in Tables 856.4 and 856.5. To properly use the plastic pipe height of fill table, the designer should be aware of the basic premises on which the table is based as well as their limitations. The design tables presuppose:

- That bedding and backfill satisfy the terms of the Standard Specifications and Standard Plan A62F, the conditions of cover, and pipe size required by the plans and the essentials of Index 829.2.
- That corrugated high density polyethylene (HDPE) pipe that is greater than 48" in size shall be backfilled with either cementitious or flowable backfill.
- That where cementitious or flowable backfill is used for structural backfill, the backfill shall be placed to a level not less than 12 inches above the crown of the pipe.
- That a small amount of settlement will occur under the culvert, equal in magnitude to that of the adjoining material outside the trench.

Table 856.4
Thermoplastic Pipe Fill Height Tables

High Density Polyethylene (HDPE) Corrugated Pipe

Size (in)	Maximum Height of Cover (ft)
12	30
15	30
18	30
24	30
30	30
36	30
42	20
48	20
54	20
60	20

High Density Polyethylene (HDPE) Ribbed Pipe

Size (in)	Maximum Height of Cover (ft)
18	24
21	24
24	24

Polyvinyl Chloride (PVC) Ribbed Pipe

Size (in)	Maximum Height of Cover (ft)
18	27
21	26
24	25
27	24
30	23
36	22
42	21
48	20

Polyvinyl Chloride (PVC) Dual Wall Corrugated Pipe

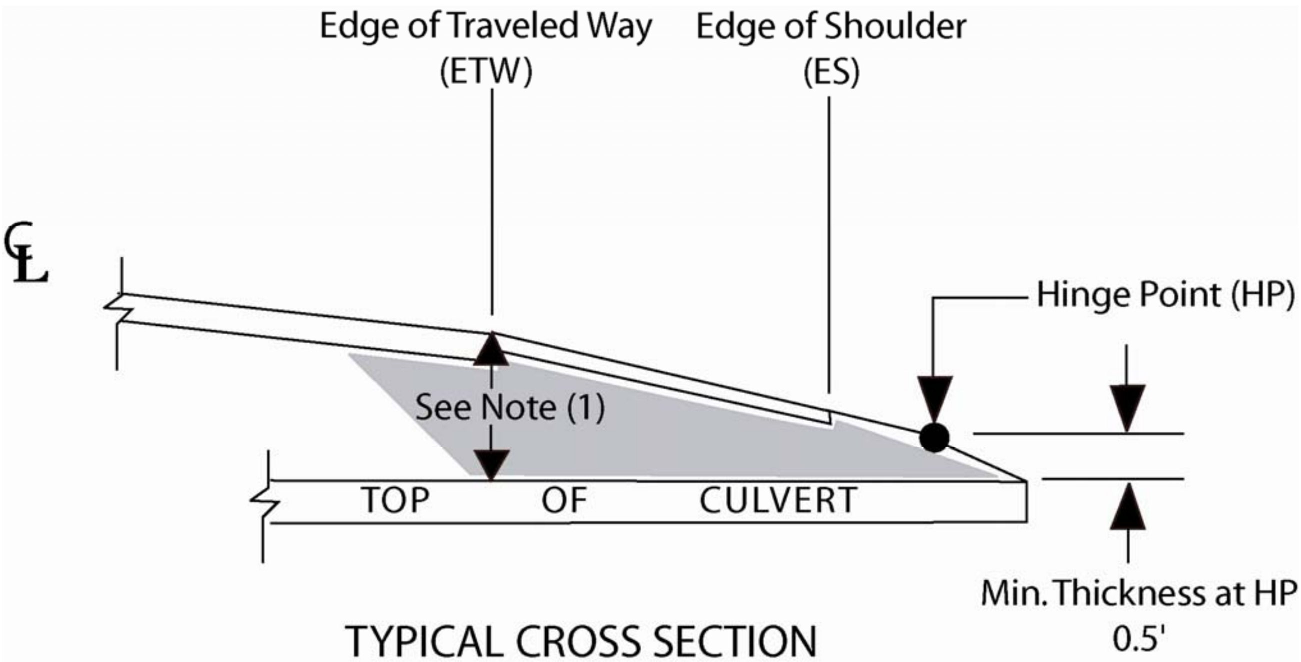
Size (in)	Maximum Height of Cover (ft)
12	38
15	36
18	40
21	39
24	40
30	40
36	40

856.5 Minimum Height of Cover

Table 856.5 gives the minimum thickness of cover required for design purposes over pipes and pipe arches. For construction purposes, a minimum cover of 6 inches greater than the roadway structural section is desirable for all types of pipe.

Table 856.5

Minimum Thickness of Cover for Culverts



MINIMUM THICKNESS OF COVER AT ETW

SURFACE TYPE	Corrugated metal pipes and pipe-arches	Structural plate pipes and pipe-arches	Reinforced concrete pipes	Plastic pipes	Cast-In-Place concrete pipes (2)
Flexible Pavements or Unpaved	1/5 (dia. or span) or 2 ft. minimum.	1/8 (dia. or span) or 2 ft. minimum	2 ft. minimum	2 ft. minimum	Structural Section plus 2 ft.
Rigid Pavements	1/5 (dia. or span) or 1.2 ft. minimum.	1/8 (dia. or span) or 1.2 ft. minimum	1 ft. minimum	2 ft. minimum	Structural Section plus 2 ft.

Notes:
(1) Minimum thickness of cover is measured at ultimate or failure edge of traveled way.
(2) See Index 852.2(1)(d) for necessary approvals prior to placing cast-in-place concrete pipes under the roadway.
(3) Table is for HS20 live load conditions only.

Where cover heights above culverts are less than the values shown in Table 856.5, stress reducing slab details available from the Headquarters Design drainage detail library using the following web address may be used: http://pd.dot.ca.gov/design/drainage.asp

Where cover heights are less than the values shown in the stress reducing slab details, contact Office of State Highway Drainage Design or the Underground Structures Branch of DES - Structures Design.

Topic 857 - Alternate Materials

857.1 Basic Policy

When two or more materials meet the design service life, and structural and hydraulic requirements, the plans and specifications must provide for alternative pipes, pipe arches, overside drains, and underdrains to allow for optional selection by the contractor. See Index 114.3 (2).

(1) *Allowable Alternatives*. A table of allowable alternative materials for culverts, drainage systems, overside drains, and subsurface drains is included as Table 857.2. This table also identifies the various joint types described in Index 854.1(1) that should be used for the different types of installations.

(2) *Design Service Life*. Each pipe type selected as an alternative must have the appropriate protection as outlined in Topic 852 to assure that it will meet the design service life requirements specified in Topic 855. The maximum height of cover must be in accordance with the tables included in Topic 856.

(3) *Selection of a Specific Material Type*. In the cases listed below, the selection of a specific culvert material must be supported by a complete analysis based on the foregoing factors. All pertinent documentation should be placed on file in the District.

- Where satisfactory performance for a life expectancy of 25 or 50 years, as defined under design service life, cannot be obtained with certain materials by reason of highly corrosive conditions, severe abrasive conditions, or critical structural and construction requirements.
- For individual drainage systems such as roadway drainage systems or culverts which operate under hydrostatic pressure or culverts governed by hydraulic considerations and which would require separate design for each culvert type.
- When alterations or extensions of existing systems are required, the culvert type may be selected to match the type used in the existing system.

857.2 Alternative Pipe Culvert Selection Procedure Using AltPipe

These instructions are general guidelines for alternative pipe culvert selection using the AltPipe computer program that is located on the Headquarters Division of Design alternative pipe culvert selection website at the following web address: http://dap1.dot.ca.gov/design/altpipe/.

AltPipe is a web-based tool that may be used to assist materials engineers and designers in the appropriate selection of pipe materials for culvert and storm drain applications. The computations performed by AltPipe are based on the procedures and California Test Methods described in this Chapter. AltPipe is not a substitute for the appropriate use of engineering judgment as conditions and experience would warrant. AltPipe establishes uniform procedures to assist the designer in carrying out the majority of the alternative pipe culvert selection functions of the Department, and is neither intended as, nor does it establish, a legal standard for these functions. Implementation of the results and output of this program is solely at the discretion of the user. The user is encouraged to first read the two informational links on the website titled 'Get More Information' and 'How to use Altpipe' prior to using the program.

Each alternative material selected for a drainage facility must provide the required design service life based on physical and structural factors, be of adequate size to satisfy the hydraulic design, and require the minimum of maintenance and construction cost for each site condition.

Table 857.2

Allowable Alternative Materials

Type of Installation	Service Life (yrs)[1]	Allowable Alternatives	Joint Type Standard	Joint Type Positive	Joint Type Downdrain
Culverts & Drainage Systems	50	ASSRP, ASRP, CAP, CASP, CSSRP, CIPCP, CSP, NRCP, SAPP, SSPP, SSRP, RCP, RCB, PPC	X	X	--
Overside Drains	50	CAP, CASP, CSP, PPC	--	--	X
Underdrains	50	PAP, PSP, PPET, PPVCP	X	--	--
Arches (Culverts & Drainage Systems)	50	ACSPA, CAPA, CSPA, RCA, SAPPA, SSPPA, SSPA	X	X	--

LEGEND

ACSPA - Aluminized Corrugated Steel Pipe Arch
ASSRP - Aluminized Steel Spiral Rib Pipe
ASRP - Aluminum Spiral Rib Pipe
CAP - Corrugated Aluminum Pipe
CAPA - Corrugated Aluminum Pipe Arch
CSSRP - Composite Steel Spiral Rib Pipe
CASP - Corrugated Aluminized Steel Pipe, Type 2
CIPCP - Cast-in-Place Concrete Pipe
CSP - Corrugated Steel Pipe
CSPA - Corrugated Steel Pipe Arch
NRCP - Non-Reinforced Concrete Pipe
PAP - Perforated Aluminum Pipe
PPC - Plastic Pipe Culvert
PPET - Perforated Polyethylene Tubing
PPVCP - Perforated Polyvinyl Chloride Pipe
PSP - Perforated Steel Pipe
RCA - Reinforced Concrete Arch
RCB - Reinforced Concrete Box
RCP - Reinforced Concrete Pipe
SAPP - Structural Aluminum Plate Pipe
SAPPA - Structural Aluminum Plate Pipe Arch
SSPA - Structural Steel Plate Arch
SSPP - Structural Steel Plate Pipe
SSPPA - Structural Steel Plate Pipe Arch
SSRP - Steel Spiral Rib Pipe
X - Permissible Joint Type for the Type of installation Indicated

NOTE:
1. The design service life indicated for the various types of installations listed in the table may be reduced to 25 years in certain situations. Refer to Index 855.1 for a discussion of service life requirements.

Step 1. Obtain the results of soil and water pH, resistivity, sulfate and chloride tests, proposed design life of culverts and make determination if any of the outfalls are in salty or brackish water. The Materials Report should include proposed design life and recommendations for pipe material alternatives. See Indexes 114.2 (3) and 114.3 (2).

Step 2. Obtain hydraulic studies and location data for pipe minimum sizes, and expected Q2-5 flow velocities. For pipes operating under outlet control, a critical element of pipe selection is the Manning's internal roughness value used in the hydraulic design. It is important to independently verify the roughness used in the design is applicable for the selected alternate materials from AltPipe. Rougher pipes may require larger sizes to provide adequate hydraulic capacities and need steeper slopes to produce desired cleaning velocities, usually however, pipe slope is maintained, and the only variable provided on the plans is pipe size.

Step 3. Determine the abrasion level from Table 852.2A from the maximum size of material that can be moved through a pipe, the expected Q2-5 flow velocities, and Table 855.2B. Field observations of channel bed material both upstream and downstream are recommended.

Step 4. Determine the maximum fill height.

Step 5. Using the AltPipe computer program that is located on the Headquarters Division of Design alternative pipe culvert selection website enter:

- Pipe diameter
- Maximum fill height
- Design service life
- pH
- Minimum resistivity
- Sulfate concentration
- Chloride concentration (for values greater than 2000, check boxes if end of culvert is exposed to brackish conditions and high tide line is below the crown of the culvert)
- Abrasion level
- 2-5-year Storm Flow Velocity (ft/sec)

Repeat step 5 as necessary and save each pipe in worksheet as needed and go to the final summary upon completion.

Step 6. The following alternatives are not included in AltPipe and will not be provided in the output Alternative pipe list: all non-circular shapes (arches, boxes etc), non reinforced concrete pipe (NRCP) and non-standard new products. Check Materials and Hydraulics reports and verify if any of these alternatives were recommended and supplement the AltPipe final summary accordingly. For reinforced concrete pipe (RCP), box (RCB) and arch (RCA) culverts, maintenance-free service life, with respect to corrosion, abrasion and/or durability, is the number of years from installation until the deterioration reaches the point of exposed reinforcement at any point on the culvert. Changes in the design may be required in relatively severe acidic, chloride or sulfate environments. The levels of these constituents (either in the soil or water) will need to be identified in the project Materials or Geotechnical Design Report. The adopted procedure consists of a formula that the constituent concentrations are entered into in order to determine a pipe service life. The means for offsetting the affects of the corrosive elements is to increase the cover over the reinforcing steel, increase the cement content, or reduce the water/cement ratio

Step 7. Table 855.2C constitutes a guide for abrasive resistant coatings in low to moderate abrasive conditions for metal pipe (i.e., Levels 1 through 5 in Table 855.2A) and is included in AltPipe. Table 855.2F constitutes a guide for minimum material thickness of abrasive resistant invert protection to achieve 50 years of maintenance-free service life in moderate to highly abrasive conditions (i.e., Levels 4 through 6 in Table 855.2A) and was not programmed into AltPipe. If pipe material thickness does not meet service life due to abrasive conditions, consideration for invert protection should be made using Table 855.2F as a guide.

Table 857.3

Example Listing of Alternative Pipe Culverts and Pipe Arch Culverts

ALLOWABLE PIPE MATERIAL AND PROTECTION

	RCP (1)	CSP				CAP				CSSRP		RCB		PLASTIC	
Designation	Size (in)	Size (in)	Thick. (in)	Bitum. Coating	Bitum. Coat Pav'd Inv.	Size (in)	Thick. (in)	Bitum. Coating	Bitum. Coat Pav'd In.	Size (in)	Thick. (in)	Span x Ht. (ft)	Max. Cover (ft)	Corrug. Inter.(3) (in)	Smooth Inter.(3),(4) (in)
18" Alt. Pipe (Type A)	18	18	0.064	No	No	18	0.060	No	No	--	--	--	--	18	18
18" Alt. Pipe (Type B)	18	24	0.064	Yes	No	24	0.060	No	No	--	--	--	--	24	18
24" Alt. Pipe (Type A)	24	24	0.064	Yes	Yes	24	0.060	No	No	--	--	--	--	24	24
24"Alt. Pipe (Type B)	24	30	0.079	No	No	--	--	--	--	--	--	--	--	--	24
24" Alt. Pipe (Type C)	--	24	0.079	No	No	24	0.135	No	No	--	--	--	--	--	--
36" Alt. Pipe (Type A)	36	42	0.064	Yes	Yes	42	0.135	No	No	36	0.064	--	--	--	--
36" Alt. Pipe (Type B)	36	36	0.079	Yes	No	36	0.105	No	No	36	0.064	--	--	--	36
48" Alt. Pipe (Type A)	48	48	0.064	Yes	Yes	48	0.105	No	No	48	0.064	--	--	--	48
48" Alt. Pipe (Type B)	48	54	0.079	No	No	54	0.135	No	No	48	0.064	--	--	--	--
49" x 33" Alt. Pipe Arch	--	49 x 33	0.079	Yes	No	49 x 33	0.105	No	No	49 x 33	0.079	--	--	--	--
60" Alt. Pipe	60	66	0.079	No	No	66	0.105	No	No	60	0.079	--	--	--	--
78" Alt. Pipe (Type A)	78	5 x 1 78	0.109	No	No	78	0.135	No	No	78	0.109	--	--	--	--
78" Alt. Pipe (Type B)	78	3 x 1 78	0.079	Yes	Yes	--	--	--	--	78	0.109	6 x 6	20	--	--

NOTES:

(1) See Standard Plan A62D for RCP strength classification and method of backfill.
(2) Coupler Type must be shown on Culvert List. (S=Standard, P=Positive, D=Downdrain)
(3) See Standard Specifications Section 64-1.03 for available and allowable plastic pipe sizes.
(4) Smooth interior plastic pipe may be either Type S or Type D HDPE; Ribbed HDPE; or Ribbed PVC pipe at the contractors option. See Section 64 of the Standard Specifications.

857.3 Alternative Pipe Culvert (APC) and Pipe Arch Culvert List

Table 857.3 shows a method of designating the type of material, size, class, thickness, protection, etc., for each type of allowable material. A similar table should be included in the plans adjacent to the drainage list when alternative materials are allowed. Because of the difference in roughness coefficients between various materials, it may be necessary to specify a different size for each allowable material at any one location. In this event, it is recommended that the material with the smallest dimension be listed as the alternative size. Refer to Drafting and Plans Manual for standard format to be used.

There may be situations where there is a different set of alternatives for the same nominal size of alternative drainage facilities. In this case the different sets of the same nominal size should be further identified by different types, for example, 18-inch alternative pipe culvert (Type A), 18-inch alternative pipe culvert (Type B), etc. No attempt to correlate type designation between projects is necessary. The first alternative combination for each culvert size on each project should be designated as Type A, second as Type B, etc.

Since the available nominal sizes for pipe arches vary slightly between pipe arch materials, it is recommended that the listed alternative pipe arch sizes conform to those sizes shown for corrugated steel pipe arches shown on Table 856.3D. The designer should verify the availability of reinforced concrete pipe arches. If reinforced concrete pipe arches are not available, oval shaped reinforced concrete pipe of a size necessary to meet the hydraulic requirements may be used as an alternative.

A

R

Y