Technical Report Documentation Page

1. REPORT No.
FHWA/CA/TL-93-14

2. GOVERNMENT ACCESSION No.

3. RECIPIENT'S CATALOG No.

4. TITLE AND SUBTITLE
Culvert Restoration Techniques

5. REPORT DATE
March 1993

6. PERFORMING ORGANIZATION
65-328

7. AUTHOR(S)
Cyrus Aryani, Joan Al-Kazily

8. PERFORMING ORGANIZATION REPORT No.
637383

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Department of Civil Engineering
California State University
Sacramento, California 95819-6029

10. WORK UNIT No.

11. CONTRACT OR GRANT No.
F90TL15

12. SPONSORING AGENCY NAME AND ADDRESS
California Department of Transportation
5900 Folsom Boulevard
Sacramento, California 95819

13. TYPE OF REPORT & PERIOD COVERED
Final 1990-1992

14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES
This study was done in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT
The objective of this project was to develop materials for use as a guide for engineers involved in the restoration of highway drainage culverts. Information on current practice was obtained from all California Department of Transportation districts, through hydraulics and maintenance engineers, from review of current literature on culvert restoration practices, and from contact with industry representatives. District engineers in other states were also surveyed to determine the extent to which culvert restoration is practiced there. Culvert restoration, as an alternative to replacement, was found to be a new approach which is not widely practiced. Since many variables affect the selection of an appropriate restoration technique, the emphasis in this report is on process rather than identification of exact solutions. Guidelines are provided to assist in classifying types of culvert wear. Appropriate techniques are identified and described, and factors to be considered when selecting the most appropriate technique are discussed.

17. KEYWORDS
culvert, restoration, repair

18. No. OF PAGES:
176

19. DRI WEBSITE LINK
http://www.dot.ca.gov/hq/research/researchreports/1989-1996/93-14.pdf

20. FILE NAME
93-14.pdf

This page was created to provide searchable keywords and abstract text for older scanned research reports.
November 2005, Division of Research and Innovation

STATE OF CALIFORNIA

DEPARTMENT OF TRANSPORTATION
DIVISION OF NEW TECHNOLOGY, MATERIALS AND RESEARCH

CULVERT RESTORATION TECHNIQUES

FHWA/CA/TL # 93 - 14
Caltrans Study # F90TL15

Performed by.....	California State University, Sacramento, Department of Civil Engineering
Supervised by.....	James A. Racin
Principal Investigator.....	Cyrus Aryani, P.E.
Co-Investigator.....	Joan Al-Kazily, P.E.
Report.....	Cyrus Aryani and Joan Al-Kazily

PAUL BENSON, Chief
Office of Environmental
and Engineering Services

REGISTERED PROFESSIONAL ENGINEER
CYRUS ARYANI
No. 40489
Exp. 3/31/95
CIVIL
STATE OF CALIFORNIA

JOHN WEST, Chief
California Department of Transportation,
Division of New Technology,
Materials and Research

CYRUS ARYANI, Professor
Department of Civil Engineering
California State University
Sacramento

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
FHWA/CA/TL-93-14		

4. TITLE AND SUBTITLE	5. REPORT DATE
Culvert Restoration Techniques	March 1993
	6. PERFORMING ORGANIZATION CODE: 65-328
7. AUTHOR(S): Cyrus Aryani, Joan Al-Kazily	8. PERFORMING ORGANIZATION REPORT NO.: 637383
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Department of Civil Engineering, California State University, Sacramento, California 95819-6029	10. WORK UNIT NO
	11. CONTRACT OR GRANT NO.: F90TL15
12. SPONSORING AGENCY NAME AND ADDRESS: California Department of Transportation, 5900 Folsom Boulevard, Sacramento, California 95819	13. TYPE OF REPORT & PERIOD COVERED: Final 1990-1992
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was done in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

The objective of this project was to develop materials for use as a guide for engineers involved in the restoration of highway drainage culverts. Information on current practice was obtained from all California Department of Transportation districts, through hydraulics and maintenance engineers, from review of current literature on culvert restoration practices, and from contact with industry representatives. District engineers in other states were also surveyed to determine the extent to which culvert restoration is practiced there. Culvert restoration, as an alternative to replacement, was found to be a new approach which is not widely practiced. Since many variables affect the selection of an appropriate restoration technique, the emphasis in this report is on process rather than identification of exact solutions. Guidelines are provided to assist in classifying types of culvert wear. Appropriate techniques are identified and described, and factors to be considered when selecting the most appropriate technique are discussed.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
culvert, restoration, repair	No Restrictions. This document is available to the public through the National Technical Information Serv. Springfield, VA 22161

19. SECURITY CLASSIF. (OF THIS REPORT)	20. SECURITY CLASSIF. (OF THIS PAGE)	21. NO. OF PAGES	22. PRICE
Unclassified	Unclassified	143	

DS-TL-1242 (Rev.6/76)

NOTICE

The contents of this report reflect the views of the Division of New Technology, Materials and Research which is responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the State of California or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

Neither the State of California nor the United States Government endorse products or manufacturers. Trade or manufacturers' names appear herein only because they are considered essential to the object of this document.

CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English Unit	Multiply By	To Get Metric Equivalent
Length	inches (in) or (")	25.40	millimetres (mm)
		.02540	metres (m)
	feet (ft) or (')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litre (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lb)	4.448	newtons (N)
	kips (1000 lb)	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (in-lb)	.1130	newton-metres (Nm)
	foot-pounds (ft-lb)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (°F)	$\frac{°F - 32}{1.8} = °C$	degrees celsius (°C)
Concentration	parts per million (ppm)	1	milligrams per kilogram (mg/kg)

ACKNOWLEDGMENTS

Our special thanks go to the following individuals for their valuable assistance and their contributions in completing this project.

Lester Gabriel	Professor Emeritus, California State University, Sacramento (CSUS)
Howard Blower	Consulting Engineer
Ralph Hwang	Professor, CSUS
Tabassum Rafique	Graduate Assistant, CSUS
Otti Cargill	Secretarial Assistant, CSUS

Descriptions of restoration techniques in Part II of this report are based in part on work done by Wilbur Smith and reported in Culvert Repair Practices Manual (Draft Final Report) April 1992.

TABLE OF CONTENTS

PART I IDENTIFICATION AND SELECTION OF TECHNIQUES — Page

1. INTRODUCTION 1

USING THIS REPORT 3

2. FINDINGS 5

3. RECOMMENDATIONS 7

4. IMPLEMENTATION 10

5. CAUSES OF DETERIORATION. 11
SOIL STRUCTURE DETERIORATION. 11
CORROSION/EROSION DETERIORATION OF CULVERT . . . 13

6. PROBLEM IDENTIFICATION AND SELECTION OF ALTERNATIVES 15
INVERT WEAR - CONCRETE CULVERTS 17
EROSION/CORROSION - STEEL, ALUMINUM, AND PLASTIC CULVERTS 19
CRACKS AND SPALLS - CONCRETE CULVERTS 21
JOINT SEPARATION - PRECAST CONCRETE CULVERTS. . . 24
STRUCTURAL PROBLEMS - METAL AND PLASTIC CULVERTS. 25

7. GUIDELINES FOR COMPARISON OF ALTERNATIVE TECHNIQUES. 27
CULVERT SIZE. 28
FACTORS AFFECTING CHOICE OF MATERIALS 28
FACTORS AFFECTING CHOICE OF LINING TYPE AND SIZE. 32
ECONOMIC CONSIDERATIONS 33
SAFETY AND ENVIRONMENTAL CONSIDERATIONS 35
AVAILABLE RESOURCES 35

TABLE OF CONTENTS (Continued)

PART II RESTORATION TECHNIQUES Page

1. REPAIR TECHNIQUES. 36
   1.1 PATCHING. 36
   1.2 CRACK SEALING 40
   1.3 JOINT REPAIR. 46
   1.4 GROUTING VOIDS IN SOIL ENVELOPE 51
   1.5 CORRUGATED METAL STRUCTURAL PLATE SEAM REPAIR . 55
   1.6 MASONRY CULVERT WALL REPAIR 63
   1.7 INVERT PAVING WITH CONCRETE 66
   1.8 INVERT PAVING WITH SHOTCRETE OR GUNITE. 74
   1.9 INVERT PLATING. 79
   1.10 INVERT COATING. 84

2. REHABILITATION TECHNIQUES. 88
   2.1 SLIP LINING 88
   2.2 FLEXIBLE TUBE LINING. 95
   2.3 CEMENT MORTAR LINING. 103
   2.4 JACKING 108
   2.5 MICRO-TUNNELING 112

REFERENCES 115

APPENDIX A SAMPLE CULVERT CONDITION REPORT FORM . . . A-1
APPENDIX B PROCESS FLOW CHARTS. B-1
APPENDIX C ECONOMIC ANALYSIS WORK SHEET C-1

TABLE OF CONTENTS (Continued)

FIGURES Page

1.5.1. METAL CULVERT PLATE SEAM REPAIR WITH REINFORCING BARS. 58

1.5.2. REPAIR OF METAL PLATE SEAMS WITH REINFORCED SHOTCRETE BEAM WITH BRACKETS PINNED ALONG THE CENTERLINE OF THE INSIDE CREST 60

1.5.3. REPAIR OF METAL PLATE SEAMS WITH REINFORCED SHOTCRETE BEAM WITH BRACKETS PINNED TO THE TANGENT PORTION OF THE CORRUGATION 61

1.7.1. INVERT PAVING METAL CULVERTS WITH UNREINFORCED CONCRETE 70

1.7.2. INVERT PAVING METAL CULVERTS WITH REINFORCED CONCRETE 73

1.9.1. INVERT PLATING METAL CULVERTS 82

2.1.1. GROUTING OF ANNULAR SPACE BETWEEN INSERTED PIPE AND CULVERT 93

2.4.1. TYPICAL EQUIPMENT SETUP FOR PIPE JACKING. 111

TABLE OF CONTENTS (Continued)

TABLES Page

7.1. MATERIAL SELECTION MATRIX FOR INVERT PAVING OR PLATING OF CONCRETE CULVERTS 29

7.2. MATERIAL SELECTION MATRIX FOR EROSION/ CORROSION OF STEEL CULVERTS. 30

PART I - IDENTIFICATION AND SELECTION OF TECHNIQUES

1. INTRODUCTION

Highway drainage culverts are an integral part of the highway system, and like other parts of the system they are subject to deterioration. Recent years have seen the development of highway pavement maintenance management systems and bridge safety management systems. These maintenance and safety management systems involve regular inspections and procedures for identification of maintenance and safety improvement techniques and projects. To date no similar system has been developed for culverts, except for those culverts actually classified as bridges.

This report documents current methods of culvert restoration. Information was obtained from CALTRANS and was supplemented by review of other reports and by discussions with manufacturers and suppliers of products and services. In this document "culverts" are separate storm runoff facilities and do not include sanitary or combined sewer facilities. Information in this report will guide hydraulics, project development, maintenance, and construction engineers in the selection of materials and techniques for restoring culverts constructed from various different materials. The inclusion of experimental materials and techniques in this report does not constitute an endorsement of the product or technique.

Culvert restoration techniques fall into two main categories which can be called repair techniques and rehabilitation techniques. Within each category there are numerous strategies which fall under the following classification:

1. Repair techniques
    - 1.1 Patching
    - 1.2 Crack sealing
    - 1.3 Joint repair
    - 1.4 Grouting voids in soil envelope
    - 1.5 Corrugated metal structural plate seam repair
    - 1.6 Masonry culvert walls repair
    - 1.7 Invert paving with concrete
    - 1.8 Invert paving with shotcrete or gunite
    - 1.9 Invert plating
    - 1.10 Invert coating

2. Rehabilitation techniques
    - 2.1 Slip lining
    - 2.2 Flexible tube lining
    - 2.3 Cement mortar lining
    - 2.4 Jacking
    - 2.5 Micro-tunneling

Jacking and micro-tunneling, which are actually culvert replacement techniques are included in this report because they are alternatives to conventional cut and cover replacement and because they do not require diversion of traffic.

Each of these strategies may be implemented in a variety of ways using different materials and possibly proprietary methods. The full range of alternative techniques is defined and described in Part 2 of this report.

Section 5 of Part I of this report describes the causes of deterioration of culverts and in Section 6 a process for problem identification is presented. This process leads to decisions regarding repair or restoration and for each type of problem a set of alternative techniques is identified. Section 7 presents guidelines for selection of the best technique for the situation.

This document is intended to facilitate the selection and implementation of the most appropriate technique for restoration of a distressed culvert. The process presented in this report is not a blueprint for a comprehensive culvert management system. Such a system would include specifications for periodic inspections, and procedures for prioritizing culvert restoration work. This report enables the user to select an appropriate technique for a specific culvert but does not provide a procedure for scheduling the work.

USING THIS REPORT

The process of selecting an appropriate culvert restoration technique must begin with identification of the problem. When the problem is known a set of feasible repair and/or rehabilitation techniques can be obtained. Finally, from this set of feasible techniques, the one which serves best under the constraints of the specific situation can be selected and implemented. The steps outlined below take the user through this process identifying the sections of this report which pertain to each step.

Step 1 Record general culvert information on the inspection form. A sample inspection form is provided in Appendix A. This step may be accomplished in a routine inspection or during monitoring inspections of a culvert that has begun to deteriorate.

Step 2 Select a set of appropriate techniques for consideration. Identify the type of wear and culvert material from the following list and go to the indicated page in Section 6 of Part I of this report.

Type of Wear and Culvert Material	Page
Invert wear - Concrete Culverts	17
Unreinforced Concrete	17
Reinforced Concrete - Bars not Exposed	17
Reinforced Concrete - Bars Exposed	17
Erosion/Corrosion - Steel, Aluminum and Plastic Culverts	19
Steel Culverts	19
Aluminum Culverts	19
Plastic Culverts	20
Cracks and Spalls - Concrete Culverts	21
Unreinforced Concrete	21
Reinforced Concrete	22
Joint Separation - Precast Concrete Culverts	24
Structural Problems - Metal and Plastic Culverts	25

Step 3 Select the best technique for the given situation. This report provides assistance to the user in the selection of the best technique. Section 7 Part I presents factors that should be considered in the comparison of alternatives. Part II presents information about each technique, listing advantages, disadvantages, difficulties and precautions, and sources of information. Part II also includes descriptions of construction methods for each technique. In Step 2 the user is directed to the pages in Section 7 Part I and in Part II that are pertinent to the case under study.

Step 4 Implement work. Review the appropriate construction method in Part II of the report and prepare to execute the work.

2. FINDINGS

Information for this report was obtained from each of the 12 California Department of Transportation (CALTRANS) Districts and from several earlier studies (Refs. 4, 10 and 11). A survey of other Western States was also conducted to determine the most common types of culvert problems and the most frequently used restoration techniques.

No clear-cut answers were found regarding the best restoration techniques for specific situations or the best time to implement such techniques. There is in fact no common agreement on what constitutes culvert restoration, often no systematic approach for early identification of culvert distress and its causes, and little experience with rehabilitation techniques such as slip lining, flexible tube lining, jacking, or microtunneling.

Restoration methods most commonly used by CALTRANS Districts include: slip lining (most districts have done at least one slip lining contract); invert paving; and invert plating. Slip lining is most commonly done with plastic pipe. Four districts provided specifications for slip lining with plastic pipe (Refs. 2, 7, 8, and 9). Two districts had performed slip lining with steel pipes (Refs. 6 and 8). Invert paving specifications were provided by one district (Ref. 9) and invert plating techniques were described by two districts (Refs. 6 and 9). District 11 provided information on an innovative technique using scrap metal guard rails for plating reinforced concrete pipe. Two districts cited cement mortar lining as a rehabilitation technique (Refs. 7 and 9).

A study on restoration techniques has recently been completed by Wilbur Smith and Associates (Ref. 4). Descriptions of some techniques found in their report were adapted for this project.

An earlier report prepared for Indiana Department of Transportation (Ref. 10) showed that, nationwide, only 15 states practice rehabilitation and that only three (including California) have fairly extensive experience. In that survey other western states indicated that they replace instead of rehabilitate culverts, or have little experience with rehabilitation. Some western states did not respond to that survey.

For this project a survey was sent to each District in the western states (Oregon, Washington, Idaho, Nevada, Utah, and Arizona). Of 39 districts contacted 23 responses were received. Twenty responses cited corrosion or rust as a common problem, 18 cited leaky joints or joint separation, and 9 cited abrasion. Other common problems were scouring, end damage by vehicles, and failure or collapse. Twenty respondents cited patching and localized repair, and eighteen cited joint repair as common repair strategies for concrete culverts. Grouting behind the culvert was less frequently used (6 respondents) and invert repair was only cited 3 times as a common repair technique. Joint repair was cited twelve times for metal culverts, invert repair was cited 9 times, and grouting behind the culvert 5 times. Responses to the questions of commonly used rehabilitation techniques confirmed the Indiana report (Ref. 10) findings. Replacement by cut and fill was cited 23 times for concrete culverts and 22 times for metal culverts, while slip lining was cited only 4 times; jacking was cited 5 times; flexible tube lining 3 times; and microtunneling once.

3. RECOMMENDATIONS

The Federal Highway Administration (FHWA) defines a bridge as

> a structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening.

Large culverts, which are classified as bridges under the above definition, must be inspected frequently in accordance with published Federal Highway Administration Guidelines (Ref. 5).

This report on culvert restoration techniques applies to culverts that are not classified as bridges. Most of these culverts will have diameters of less than six feet but some may have diameters up to 20 feet.

The scope of the inspections specified in the FHWA Culvert Inspection Manual (Ref. 3) is extensive and while this broad scope is necessary for large culverts, it is costly. Smaller culverts may be inspected at less frequent intervals and may require a less detailed inspection. It is suggested in the FHWA Culvert Inspection Manual, and recommended here, that smaller culverts be inspected as follows:

New culverts - inspect once a year for first two years

Culverts with history of significant problems - inspect annually or every 6 months or as deemed necessary

All other culverts - inspect periodically as determined by agency budget.

Inspections should be carried out using the Standard Culvert Condition Report Form provided in Appendix A or a similar form developed by District Engineers.

While routine inspection of all culvert structures regardless of shape or size must be considered for an effective maintenance and efficient rehabilitation program, it is imperative that critical structures be given priority in the program. Critical structures could be identified as those whose failure, either hydraulically or structurally, would result in severe damage to the fill and possibly even loss of life. Such structures could include boxes, arches, long span structures, large diameter circular pipe culverts, and others with minimum cover.

It is recommended that culverts in each District's highway drainage system be inventoried and inspected at regular intervals. This guide for selection of repair or rehabilitation strategy can be used with or without such systematic inspections. It is recommended that District engineers use this report to develop procedures for culvert inspection and rehabilitation decision making in their District.

The restoration techniques outlined in Part II of this report are recommended for restoration of culverts. New or experimental techniques are identified as such in this report. All new or experimental culvert materials, whether used for restoration or as the culvert itself, must be reviewed by the Caltrans Culvert

Committee. If new or experimental culvert materials are encountered, contact:

Caltrans State Hydraulic Engineer
Office of Project Planning and Design
650 Howe Avenue
Sacramento, CA 95825
916-263-1026

Culvert restoration work may be undertaken directly by the Maintenance Division or jointly by the Maintenance and the District Hydraulics Division. Regardless of the channels through which the work is finally implemented, it is expected that the maintenance group will consult extensively with District Engineers during the restoration technique selection process. Before a rehabilitation technique is selected and implemented it will be important to identify whether a culvert is structurally sound and whether hydraulic needs have changed or may change in the near future. The process for monitoring culverts which have begun to deteriorate is presented in Section 6 of Part I and Appendix B of the report.

In a comprehensive culvert management system one additional step should be added to the process described in this report, namely, monitoring of repair and rehabilitation work. This monitoring, which will provide valuable information for future decision making, is included on flowcharts in Appendix B of this report, but is not discussed in the text.

4. IMPLEMENTATION

Copies of this report will be distributed to FHWA, Caltrans Districts, and appropriate Headquarters Offices for their use. Information in this report can be used to guide the selection of materials and techniques for restoring culverts. Specific District Hydraulic Engineers or others cited in the text may be contacted for detailed information

5. CAUSES OF DETERIORATION

The deterioration of a culvert may involve the entrance or outlet structures (headwall and endwall), the conduit, the soil surrounding the conduit, or any combination of these. The following outline will provide more specific details on causes of soil structure and conduit deterioration.

SOIL STRUCTURE DETERIORATION

Headwall

Entrance conditions that cause erosion of the embankment and result in disjointing of sectional pre-cast conduit, or flotation or collapse of flexible conduit may include any combination of the following:

1. Misalignment of the culvert structure and the existing drainage channel.

2. Failure of headwall or entrance structure due to excessive foundation settlement.

3. Settlement and/or expansion of the embankment fill behind the headwall.

4. Conduit sections not adjoined properly to transfer the longitudinal loads between segments.

5. Debris clogging the entrance during severe storm conditions.

Endwall

The endwall or outlet structure, like the headwall, requires consideration of the downstream channel to prevent erosion and structure failure that may result in loss of embankment, or impact the environmental balance especially to fish migration. The following specific factors may cause deterioration of the endwall:

1. Downstream erosion due to high discharge velocities.

2. Failure of endwall due to foundation settlement and/or undermining.

3. Settlement and/or expansion of the embankment fill upstream from the headwall.

4. Conduit sections not adjoined properly to transfer the longitudinal load between segments.

Conduit

Integrity of the soil envelope surrounding the conduit is a critical factor to both the roadway embankment and the culvert barrel. The following factors may result in degradation of the supporting soil envelope.

1. Coarse and/or poorly compacted backfill material that invites a water channel (piping) under or alongside the conduit.

2. Infiltration of backfill fines into the conduit at poorly aligned or open joints in the structure.

3. Exfiltration of the stream flow from the conduit into

the soil envelope.

4. Differential settlement of the embankment.

CORROSION/EROSION DETERIORATION OF CULVERT

General: As previously noted the soil envelope deterioration from the original as-built condition may result in degrading the conduit from its as-built design condition. The interdependency of conduit and soil envelope integrity is equally true when corrosion/erosion is the basic cause of conduit deterioration.

Corrosion

Caltrans pioneered research test methods for predicting maintenance free service life by observation of thousands of culvert structures. pH and soil minimum resistivity are the basic factors for estimating the life of metal culverts. For concrete structures, three environmental factors are combined to estimate service life, these being pH, sulfate, and the chloride-ion concentrations. Proper application of the results of tests at the project design stage will result in the selection of materials that generally exceed the design life expectancy when corrosion is the paramount concern. Accelerated corrosion could possibly occur due to the following factors:

1. Environmental changes that modify the watershed runoff. Examples include forest fires and acid rain effluent from mines, etc.

2. Corrosive structure backfill.

3. Damage of the conduit's protective coatings prior to, during, and after construction.

Erosion

General: Practically all culvert and storm drains are subjected to erosive forces of bed load carried by the stormwater. Factors that contribute to the erosive degradation of the structures inverts are as follows:

1. Slope of the upstream channel and aggregate transported by the stream in flood stage.

2. Entrance design of the structure, i.e., debris structure.

3. Grade of the conduit and velocity of flow.

4. Aggregate transported:

   a. size
   b. hardness
   c. shape

5. Conduit material: steel, concrete, aluminum and plastic.

6. PROBLEM IDENTIFICATION AND SELECTION OF ALTERNATIVES

The selection of a set of feasible techniques for culvert restoration, and the subsequent selection of the best technique, is based on factors which fall into the following categories: Culvert material; Condition of culvert; Structural requirements; Hydraulic needs; Site conditions; Safety and environmental factors; Economic factors; and Available resources.

The first four categories control the selection of sets of appropriate alternative techniques, while the latter four influence the selection of the best technique for the situation. This section of Part I of the Guide addresses the first four categories, while Section 7 deals with the latter four.

This report provides guidelines based only on the condition of the culvert and culvert material. District engineers should assess the structural and hydraulic needs of the specific culvert to determine whether any (or all) of the alternative techniques should be eliminated because of structural or hydraulic inadequacy. In some cases rehabilitation may be ruled out in favor of a new installation to provide additional hydraulic capacity. Hydraulic problems created by the alignment of the culvert could lead to a decision to replace instead of rehabilitate. Hydraulic problems caused by poor inlet or outlet structures can however be corrected when a culvert is restored. This report does not provide guidance for the hydraulic analysis of culverts. If the hydraulic capacity of the existing culvert is in question, or if restoration techniques which decrease the cross section and/or increase the surface roughness are being considered, the District hydraulic engineer should be consulted. Users of this report may refer to FHWA Hydraulic Design Series Number 5 entitled "Hydraulic Design of Highway Culverts" for guidance on culvert hydraulics.

Future plans for roadway reconstruction at the culvert site should also be investigated. If a reconstruction project is planned it may be desirable to replace the culvert as part of that project. In this case short-term repair strategies may be favored over long-term rehabilitation of the culvert.

In this section of the report culverts are classified by type of problem and material as follows:

Invert wear - Concrete Culverts
- Unreinforced Concrete
- Reinforced Concrete - Bars not Exposed
- Reinforced Concrete - Bars Exposed

Erosion/Corrosion - Steel, Aluminum and Plastic Culverts
- Steel Culverts
- Aluminum Culverts
- Plastic Culverts

Cracks and Spalls - Concrete Culverts
- Unreinforced Concrete
- Reinforced Concrete

Joint Separation - Precast Concrete Culverts

Structural Problems - Metal and Plastic Culverts

In the following pages the physical evidence of each type of problem is discussed. Appropriate restoration techniques are listed for each type of problem and factors to be considered in selecting between alternative methods and materials are identified. In Appendix B flow charts are presented for the inspection and decision making process appropriate to each type of culvert material and problem. The flow charts identify data that should be obtained and reported to the District Hydraulic Engineer or other responsible official (referred to as "District" in Appendix B). Sample culvert condition report forms are provided in Appendix A.

INVERT WEAR - CONCRETE CULVERTS

Unreinforced Concrete

Invert wear is indicated by rutting. Once rutting has begun wear should be expected to occur rapidly, thus the presence of rutting indicates the need for frequent inspections to monitor progress of wear. If the maximum loss of thickness is greater than 25% of the original thickness, need for restoration is indicated. (See flow chart pg. B-2.)

Reinforced Concrete - Bars Not Exposed

Invert wear is indicated by rutting or rust stains at invert of culvert. Once rutting or corrosion of the steel reinforcement has begun, degradation of the invert should be expected to proceed at an accelerated rate. Thus the presence of rutting or rust stains indicates the need for frequent inspections to monitor progress of wear. A decision to implement restoration will depend on the extent of the deterioration and should be based on a profile of the wear. (See flow chart pg. B-3.)

Reinforced Concrete - Bars Exposed

Although the bond between reinforcement and concrete may be broken before the bars are exposed, there is no question that bond is absent when bars are exposed. This has very serious structural implications in that the steel is no longer functioning as was intended. The concrete alone should never be assumed to be capable of carrying the loads on the culvert. When culverts have deteriorated to this stage, the inspection may include a detailed description of the exposed bars, an alignment survey of the fill, and inspection holes to probe for soil loss at the invert. (See flow chart pg. B-4.)

Restoration Techniques for Invert Wear of Concrete Culverts

Invert wear restoration techniques for both unreinforced and reinforced concrete culverts are listed below. Information about each technique, including attributes, advantages, disadvantages, information sources, and construction methods are provided in Part II of this report on the pages indicated below.

Technique	Pages
(1) Pave invert with:	
Portland cement concrete	66 and 69
Wire mesh reinforced concrete	66, 71, and 73
Fiber reinforced concrete	66 and 69
High strength concrete	66 and 69
Shotcrete	74
(2) Plate with steel	79
(3) Coat with:	
Oxidized Asphalt	84
Polymer	84
Epoxy	84
(4) Slip lining	88
(5) Flexible tube lining	95
(6) Cement mortar lining	103
(7) Jacking	108
(8) Microtunneling	112

Selecting Between Methods and Materials

In selecting the appropriate technique for restoration of concrete culverts with invert wear the following should be considered:

(a) Structural integrity of existing culvert (pg. 27)
(b) Hydraulic need, problems, and changes (pg. 27)

(c) Future highway reconstruction plans (pg. 27)
(d) Culvert size (pg. 28)
(e) Factors (including bed load and water pH) affecting choice of materials (pg. 28)
(f) Selection of lining type and size (pg. 32)
(g) Economic factors (pg. 33)
(h) Safety and environmental factors (pg. 35)
(i) Available resources (pg. 35)

EROSION/CORROSION - STEEL, ALUMINUM AND PLASTIC CULVERTS

Steel Culverts

Wear is first indicated by erosion of the galvanized outer layer of the corrugated steel. Once this layer has been penetrated by the abrasive action of the gravel bed load, the unprotected steel should be expected to deteriorate rapidly. After wear is first noted, a culvert should be inspected frequently to monitor the progress of the wear. In addition to recording the location and extent of the wear, inspections should also include a search for evidence of piping. (See flow chart pg. B-5.)

Aluminum Culverts

Abrasion of an aluminum culvert is an indication of inappropriate selection of culvert material. Use of aluminum should also be limited to pH greater than 5.5 and less than 8.5. Aluminum culverts should also not be in direct contact with any portland cement slurry (Ref. 1). The existence of any of these conditions should therefore be carefully noted in an inspection. If damage has occurred the location and extent of the damage should be recorded and the inspection should include a search for evidence of piping. (See flow chart pg. B-6.)

Plastic Culverts

Invert wear in plastic culverts is difficult to detect. There is unlikely to be rutting or visual evidence of corrosion. The worn invert will appear smooth and somewhat polished. The absence of circular or spiral patterns which result from the manufacturing process may be the only visible evidence of invert wear. In addition to recording the location and extent of damage, inspections should include a search for evidence of piping. (See flow chart pg. B-7.)

Restoration Techniques for Erosion/Corrosion of Steel, Aluminum, and Plastic Culverts

Restoration techniques are listed below. Information about each technique, including attributes, advantages, disadvantages, information sources, and construction methods are provided in Part II of this report on the pages indicated below:

Technique		Page
(1)	Coat with:	
	Oxidized asphalt	84
	Polymer	84
	Epoxy	84
(2)	Pave with:	
	wire mesh reinforced concrete	66 and 71
	fiber reinforced concrete	66 and 69
	unreinforced concrete	66 and 69
(3)	Plate with steel	79
(4)	Slip lining	88
(5)	Flexible tube lining	95
(6)	Jacking	108
(7)	Microtunneling	112

Selecting Between Methods and Materials

In selecting the appropriate technique for erosion/corrosion problems the following should be considered:

(a) Structural integrity of existing culvert (pg. 27)
(b) Hydraulic need, problems, and changes (pg. 27)
(c) Future highway reconstruction plans (pg. 27)
(d) Culvert size (pg. 28)
(e) Factors (including bed load and water pH) affecting choice of materials (pg. 28)
(f) Factors affecting choice of lining type and size (pg. 32)
(g) Economic factors (pg. 33)
(h) Safety and environmental factors (pg. 35)
(i) Available resources (pg. 35)

CRACKS AND SPALLS - CONCRETE CULVERTS

Unreinforced Concrete

Hairline cracking (less than one sixteenth of an inch) does not affect the stability of an unreinforced concrete culvert. Inspections should include notation of crack orientation, location, width, and length for cracks greater than one sixteenth of an inch in width. It may be necessary to remove caked materials from the culvert invert and to lightly dampen the surface in order to discover cracks. Crack orientation is important because circumferential cracks are not serious unless there is evidence of soil migration while longitudinal cracks over one sixteenth of an inch in width may lead to loss of structural strength. Inspections should include notation of evidence of soil migration for both circumferential and longitudinal cracking.

If cracks greater than one sixteenth of an inch appear at both the crown and the invert, the inspection should include mapping of the cross-sectional inner surface. The geometry of this surface will be useful in determining whether there is significant cracking of the outer wall at the springline. Inspectors should NEVER dig a test pit to examine the condition of the wall from outside the culvert because this could lead to structural problems. (See flow chart pg. B-8.)

Reinforced Concrete

Cracking in reinforced concrete culverts may be accompanied by rust stains and/or by spalling of concrete. Spalling may or may not result in exposure of reinforcing bars. While bond between reinforcing bars and concrete may be broken before spalling occurs, there is no question that bond is absent when spalling and/or exposed reinforcing bars are evident. Loss of bond between reinforcing bars and concrete has very serious structural implications. Cracks and spalls at the crown or invert of a reinforced concrete pipe culvert are of special significance and imply structural deterioration. Mapping of diagonal cracks should define the beginning and ending points of the crack.

Inspections should include measurement of crack length and width and identification of its location by distance from inlet and degrees from invert. It may be necessary to remove caked material from the invert and slightly dampen the surface in order to discover cracks. Inspections should also include description of rust stain patterns accompanying the cracks. If spalling or exposure of reinforcing is present, this should also be noted and described. Any misalignment of the bars should also be noted. (See Flow Chart pg. B-9.)

Restoration Techniques for Cracks and Spalls

Restoration techniques are listed below. Information about each technique, including attributes, advantages, disadvantages, information sources, and construction methods are provided in Part II of this report on the pages indicated below:

Technique		Page
(1)	Patching	36
(2)	Crack sealing	40
(3)	Grouting voids in soil envelope (unreinforced culverts)	51
(4)	Slip lining	88
(5)	Flexible tube lining	95
(6)	Jacking	108
(7)	Microtunneling	112

Selecting Between Methods and Materials

In selecting the appropriate technique for repair of cracks and spalls the following should be considered:

(a) Structural integrity of existing culvert (pg. 27)
(b) Hydraulic need, problems, and changes (pg. 27)
(c) Future highway reconstruction plans (pg. 27)
(d) Culvert size (pg. 28)
(e) Factors (including bed load and water pH) affecting choice of materials (pg. 28)
(f) Factors affecting choice of lining type and size (pg. 32)
(g) Economic factors (pg. 33)
(h) Safety and environmental factors (pg. 35)
(i) Available resources (pg. 35)

JOINT SEPARATION - PRECAST CONCRETE CULVERTS

Separation of joints may occur between culvert segments or between the culvert and its inlet or outlet. The latter may be expected to lead to embankment washout and failure. Another very serious condition involving joint separation is "end drop off" which means that the end segment of pipe at the inlet or outlet becomes totally separated from the culvert. Repair of end drop off is very difficult thus early detection of joint separation is particularly important for these end joints.

Inspections should include notation of the location of the affected joint. The nature of the separation should be noted. If piping is present there is possibility of serious structural failure and/or embankment instability. When piping is detected further information should be obtained and the inspection may include preparation of topographic cross sections and a survey of the horizontal and vertical alignment of the culvert. An estimation of the amount and reach of embankment loss may be necessary. (See flow chart pg. B-10.)

Restoration Techniques for Joint Separation

Restoration techniques are listed below. Information about each technique, including attributes, advantages, disadvantages, information sources, and construction methods are provided in Part II of this report on the pages indicated below:

Technique	Page
(1) Joint Repair	46
(2) Grouting Voids in Soil Envelope	51
(3) Slip Lining	88
(4) Flexible Tube Lining	95
(5) Jacking	108

(6) Microtunneling 112

Selecting Between Methods and Materials

Selection between repair (joint repair and grouting), relining, or replacement by microtunneling is influenced by the following factors:

(a) Structural integrity of existing culvert (pg. 27)
(b) Hydraulic need, problems, and changes (pg. 27)
(c) Future highway reconstruction plans (pg. 27)
(d) Culvert size (pg. 28)
(e) Factors (including bed load and water pH) affecting choice of materials (pg. 28)
(f) Factors affecting choice of lining type and size (pg. 32)
(g) Economic factors (pg. 33)
(h) Safety and environmental factors (pg. 35)
(i) Available resources (pg. 35)

STRUCTURAL PROBLEMS - METAL AND PLASTIC CULVERTS

Structural problems should be expected when a flexible culvert is subjected to large deflections. Deflections of less than five percent should be noted and the culvert should be reinspected at timely intervals to determine whether the deflection is increasing. Deflections of more than five percent may lead to structural problems and may be accompanied by seam separation and/or buckling. If these problems are noted their location, by distance from inlet and degrees from invert, should be noted and the length of the horizontal and vertical axes of the culvert pipe should also be recorded. The location of all distortions should also be noted and distortions should be described. The inspector should also look for and record any evidence of backfill migrating into the pipe or the earth movement. The

inspection should also include a survey of the horizontal and vertical alignment of the fill. Before work is undertaken it may also be necessary to probe to estimate material loss. (See flow chart pg. B-11.)

Restoration Techniques for Structural Problems of Metal or Plastic Culvert

Techniques are listed below. Information about each technique, including attributes, advantages, disadvantages, information sources, and construction methods are provided in Part II of this report on the pages indicated below:

Technique	Page
(1) Joint Repair	46
(2) Grouting Voids in Soil Envelope	51
(3) Jacking	108
(4) Microtunneling	112

Selecting Between Methods

The decision to repair (grout voids and repair joints) versus replace the culvert by jacking or microtunneling is dependent in part on the structural integrity of the culvert. If the culvert must be replaced, cut and cover should be considered as an alternative and the decision will be influenced by cost and the need to maintain traffic flow during construction. Relining by slip lining or flexible tube lining was not included on the above list because these methods cannot be used on culverts with excessive deflection. The methods may be considered for culverts with small deflections.

7. GUIDELINES FOR COMPARISON OF ALTERNATIVE TECHNIQUES

In selecting the appropriate restoration technique the structural integrity of the existing culvert should be considered. Another important factor to be considered before deciding to rehabilitate a culvert is the hydraulic need and hydraulic problems associated with the existing culvert. If hydraulic problems exist, or if hydraulic needs have changed since the culvert was first installed, replacement may be considered as an alternative to restoration. The replacement alternative should be compared with restoration plus hydraulic capacity enhancement such as reconstruction and improvement of the inlet structure (if the culvert operates under inlet control). Engineers should also consider future highway reconstruction plans. If culvert replacement can appropriately be included in a future highway reconstruction project a short-term repair technique may be adequate to extend the culvert life until reconstruction is undertaken.

Numerous other factors influence the selection between alternatives. They have been broken down into the following categories:

1. Culvert size
2. Bed load and water pH and other factors affecting choice of materials
3. Factors affecting choice of lining type and size
4. Economic considerations
5. Safety and environmental considerations
6. Available resources

For the most part these guidelines are presented in discussion format since many of the factors to be considered are qualitative rather than quantitative. Where possible quantitative decision making aids are included.

CULVERT SIZE

Culvert size influences selection of restoration technique because repairs requiring personnel to enter the culvert cannot be used if the culvert is too small. California's Occupational Safety & Health Administration specifies 30 inches as the minimum culvert opening for entry by personnel. However, it is difficult to work in culverts with diameter or width and height less than 36 inches.

FACTORS AFFECTING CHOICE OF MATERIALS

Bedload and water pH

Invert wear in all types of reinforced concrete culverts can be treated by a wide range of alternative repair or rehabilitation techniques, using various different materials. The bed load and water pH will determine which of these materials are acceptable at a specific location. The following matrix (Table 7.1) should be used to select the acceptable materials for invert paving or plating of concrete culverts.

TABLE 7.1

MATERIAL SELECTION MATRIX FOR INVERT PAVING OR PLATING OF CONCRETE CULVERTS

Condition	Acidic Runoff	Alkali Runoff	Rock Abrasion	Sand Abrasion
Repair/ Rehabilitation Strategy				
1. Pave with PCC		X		
2. Pave with fiber reinforced PCC		X		
3. Pave with high-strength concrete		X	X	X
4. Pave with PCC and coating with oxidized asphalt	X			
5. Pave with shotcrete		X		
6. Plate with steel		X	X	X
7. Coat with oxidized asphalt	X			

Note: X indicates the strategy is acceptable for the conditions.

Bedload and water pH may also influence the choice of repair/rehabilitation strategies for flexible steel culverts with erosion/corrosion problems. The following matrix should be used to select acceptable materials.

TABLE 7.2

MATERIAL SELECTION MATRIX FOR EROSION/CORROSION OF STEEL CULVERTS

Condition	Acidic Runoff	Alkali Runoff	Rock Abrasion	Sand Abrasion
Repair/Rehabilitation coating material				
Resin coating	X	X		X
Reinforced concrete paving		X	X	X
Bituminous coating	(Polymer asphalt pipe coating and paving are under development and test (Ref. 27))			

Aluminum culverts should not be used under abrasive or alkaline conditions (see pg. 19). If aluminum culvert inverts have been subjected to erosion or corrosion the appropriate invert repair technique is reinforced concrete paving. Coating of aluminum culverts is not recommended (Ref. 1). Rehabilitation techniques such as slip lining should also be considered when an aluminum culvert has been inappropriately installed in an abrasive or alkaline environment.

Appropriate materials for common restoration techniques

Patching: Portland cement concrete is normally used for

patching. However, various additives may be used to increase strength and reduce setting time when needed. Alternatives are also available for bonding the patch to the existing culvert. No advantages or disadvantages for these alternative bonding materials have been identified.

Crack sealing: The major choice for crack sealing is between a flexible and a non-flexible sealant. A flexible sealant should be used for cracks that are moving and which can be allowed to continue to move. If cracks have stabilized or must be stabilized a non-flexible material such as portland cement concrete or an epoxy structural adhesive should be used.

External grouting: Material for grouting should not shrink, segregate, or otherwise create additional problems. Portland cement material is adequate for most culvert grouting. If high fluid pressure is expected in the areas to be grouted chemical or foaming grouts may be used.

Slip lining: In theory any prefabricated pipe can be inserted inside an existing culvert to provide a complete new lining. However, those most commonly used are plastic and corrugated metal pipes.

Plastic pipe without interior corrugations provides the desired smoothness which may permit flow capacity to be maintained with a smaller cross section. Although corrugated metal or plastic pipe may be used for slip lining it should be noted that it is very difficult to insert a corrugated liner into a corrugated culvert.

Other materials such as reinforced concrete or ductile iron may be considered for slip lining. (When such rigid pipes are used the process is sometimes referred to as jacking.) However, these pipes are heavy and difficult to handle. Concrete pipes may be appropriate in areas where there is a high risk of fire.

Cement-mortar lining: Material selection here focuses on admixtures which can be used to facilitate placement, minimize drying and shrinkage cracks, and improve durability. Air entrainment may be used to provide additional freeze-thaw resistance.

Flexible tube lining: Flexible tube linings can be inserted by inversion or as folded tubes. The most commonly used material for inversion lining is resin impregnated felt. A polyurethane coating can be applied to the interior of the felt tube for increased smoothness. PVC or polyethylene flexible pipes have been used for the folded tube method of insertion.

FACTORS AFFECTING CHOICE OF LINING TYPE AND SIZE

Choice between slip lining, flexible tube lining, and cement mortar lining

Slip lining will generally be preferred to flexible tube lining because of its lower cost. In difficult situations where the existing culvert barrel has changes in alignment, or when the needed hydraulic capacity cannot be obtained by slip lining, cement mortar lining or the flexible tube method can be considered as an alternative. When considering slip lining as an alternative careful attention should be paid to the space needed for equipment at the insertion end of the culvert.

Pipe sizes for slip lining

The required pipe diameter for slip lining is influenced by hydraulic need and desirable annular space between the liner and the existing culvert. There should be adequate clearance between the outside diameter of the slip liner and the minimum inside dimension of the existing culvert. As a guideline the annular space (total for both sides or top and bottom of culvert) may be

considered to be at least 10% of the inside diameter of the existing culvert. Engineering judgment should be used in selecting the closest available pipe size to that which provides the appropriate annual space. A hydraulic check must be made to determine whether this size pipe can handle the required flow rate.

ECONOMIC CONSIDERATIONS

If two alternatives with equal expected lives are being compared the economic criteria is simply to select the alternative with the lowest initial cost. In some situations it may be appropriate to compare two alternatives with different expected lives. Two cases should be considered. These are: (a) analysis period relatively long; and (b) analysis period short. The analysis period should be taken to be the required life of the culvert. The procedure for each of these cases is as follows:

Analysis period long (possibly infinite): The repair or rehabilitation techniques are assumed to be repeated many times at the end of their expected lives.

Method: Compute and compare the equivalent uniform annual cost (EUAC) of each alternative

$$EUAC = I\ (A/P,\ i,\ n)$$

where:

I = Initial cost

i = Interest (or discount) rate normally used by the District

n = Expected life of the repair strategy

(A/P, i, n) = Capital recovery factor:

$$\frac{i(1+i)^n}{(1+i)^n - 1}$$

The alternative with lowest EUAC is selected.

<u>Analysis period short:</u> The repair or rehabilitation techniques are assumed to be repeated as often as needed.

Method: Compute and compare the present worth of costs (PWC) of each alternative.

PWC = I + I (P/F, i, n) + I (P/F, i, 2n) + ...

where:

I, i, n, and p are as previously defined

(P/F, i, n) = The Single Sum Present Worth Factor:

$$\frac{1}{(1+i)^n}$$

The alternative with the lowest PWC is selected.

(Note: The number of terms in the PWC equation is equal to the number of times the strategy would need to be repeated in the analysis period.)

An economic analysis work sheet is provided in Appendix C. The factors (A/P, i, n) and (P/f, i, n) are available in standard engineering economics texts.

SAFETY AND ENVIRONMENTAL CONSIDERATIONS

The safety aspects of each alternative being considered must be thoroughly investigated. Many of these are listed for each alternative in Part II of this report. If two alternatives are equally acceptable from all other points of view then the one which creates fewer safety problems is obviously preferred. Particular attention should be paid to safety problems involving high pressure hoses, heat, and chemicals which produce toxic fumes.

Alternatives may sometimes be eliminated because of their effect on the environment. Some culverts may carry stream flows that fish utilize as their travel ways. Repair or rehabilitation strategies should not create conditions detrimental to the survival of these fish, nor should any materials contain ingredients toxic to fish.

AVAILABLE RESOURCES

Selection of repair or rehabilitation strategies and timing of work is always influenced by budgetary constraints. It may be desirable to develop priority lists of rehabilitation projects and consideration should be given to early intervention at a lower cost to prolong the life of a culvert.

If work is to be done by the maintenance group, selection of the best technique will also be influenced by available equipment.

PART II - RESTORATION TECHNIQUES

1. REPAIR TECHNIQUES

1.1 PATCHING

Application:

Precast concrete and cast-in-place concrete culverts.

Definition:

Patching is the application of a cement based material to replace sections of portland cement concrete that have spalled or broken away from the inside surface of the culvert.

Alternative materials:

- Patch - portland cement concrete
- Additives - water reducing admixture
  - latex additive
  - non-chloride accelerators to reduce setting time and increase strength
- Bonding layer - cement grout
  - cement latex grout
  - epoxy resin

Alternatives to patching:

Slip lining; flexible tube lining; cement mortar lining; replacement.

Advantages of patching:

- Low cost
- Low resource commitment, accomplished by maintenance personnel

Disadvantages of patching:

- May not last long
- Must inspect periodically to see if patch is holding - note additives which reduce setting time may increase shrinkage thus decreasing bond
- If patch comes off it will lead to worsening conditions

Difficulties and precautions:

- Culvert must be empty and patching area dry
- Patch will come off quickly if work is not well done

Criteria for use of patching:

- Depth of spalling
- Extent of spalling
- Extent of prior patching
- Desired future life of culvert
- Size of culvert

Sources of information:

- Federal Highway Administration (Ref. 4)
- American Concrete Institute (Ref. 16)

Construction Methods

The following procedure may be used to patch spalled, delaminated, and broken areas of Portland cement concrete culverts over three feet in diameter or height. The patching material is Portland cement with additives if necessary.

1. Determine the exact boundaries of the distressed concrete. Delaminated areas may be detected by tapping with a hammer or steel rod. A hollow sound is produced in the delaminated area.

2. If the damaged areas are below the water level, divert flow away from the culvert during patching.

3. Remove delaminated and/or broken concrete from the distressed area. It may be desirable to make a 3/4 inch deep sawcut around the area to be patched and remove all material within the boundaries of this sawcut. For delaminated and spalled areas, the edge of the repair should extend 12 to 18 inches into good concrete to ensure that all cracked concrete is removed. Deteriorated concrete may be removed with power driven hand tools. A 15 lb chipping hammer may also be useful, particularly around reinforcing bars. Care must be taken to not apply heavy vibrations to reinforcing bars because this could break the bond with concrete.

4. Clean the repair area by air or sand blasting to remove all dust and debris. Water must be used for final cleaning, and the damaged area must be moist when patching work is in progress.

5. Apply the cement or cement-latex grout or epoxy resin bonding material to all surfaces and to reinforcement in the area to be repaired.

6. Place the Portland cement concrete in the distressed area in accordance with California Department of Transportation Standard Specifications (Section 51-1.09). The material should be placed before the bonding layer (Step 5) exceeds the set time limits appropriate to the material. The patching material should then be struck off, finished, and edged as required.

7. In the case of Portland cement grout, cover the patched area with wet burlap or a moisture barrier and allow it to cure without disturbance in accordance with California Department of Transportation Standard Specifications (Section 90-7).

1.2 CRACK SEALING

Application:

Precast concrete and cast-in-place concrete culverts.

Definition:

Crack sealing is the application of one of several alternative materials to fill cracks in concrete culverts. The sealant may be flexible or non-flexible.

Alternative materials:

- Flexible sealant (for cracks that are moving and which can be allowed to continue to move):
- Non-flexible sealant (for cracks that have stabilized or for moving cracks which must be stabilized):
  - Portland cement mortar or grout (for cracks greater than one thirty secondth of an inch)
  - Structural adhesives which provide tensile and shear strength. (Epoxy systems which may or may not be filled with aggregate or other materials.)

Alternatives to crack sealing:

Slip lining; flexible tube lining; cement mortar lining; replacement.

Advantages of crack sealing:

- Low cost
- Low resource commitment

- Protects reinforcing

Disadvantages of crack sealing:

May be only a cosmetic repair if basic cause of the cracking is not determined and treated with appropriate pressure grouting.

Difficulties and precautions:

- Difficult to adequately clean cracks
- For some sealants crack must be dry

Criteria for use of crack sealing:

- Width of cracks
- Stability of cracks
- Depth of cracks
- Extent of cracking
- Extent of prior repairs
- Desired future life of culvert

Safety precautions:

Toxicity of solution grouts should be evaluated to prevent any harm to the environment.

Sources of information:

- Federal Highway Administration (Ref. 4)

- Pennsylvania Department of Transportation, for repair by injection of epoxy adhesive (Ref. 28)

- Pressure Grout Company, for grouting (Ref. 29)

- GKN Hayward Baker, for grouting (Ref. 20)

Construction Methods

The following three alternative procedures apply to the repair of cracks in Portland cement concrete culverts over three feet in diameter or height.

1.2.1 Installation of a flexible sealant.

The following is a general procedure for filling a crack with a flexible sealant. The manufacturers of such sealants may have more specific recommendations for their particular materials.

1. If cracks are below the water line divert flow away from the culvert during repairs.

2. Clean the surface of the concrete.

3. Route a groove into the surface of the crack to serve as a reservoir for the sealant.

4. Clean concrete dust and debris out of the crack by sand blasting, air-water jet, or both, and remove standing water.

5. Fill the crack with sealant by pressure injection or trowelling.

6. Scrape excess sealant off the concrete surface, so that the surface is smooth.

1.2.2 Installation of Portland cement grout.

Cracks between one thirty secondth of an inch and one quarter of an inch wide may be repaired by filling with Portland cement grout, as described below. Finer cracks would require pressure grouting or epoxy grouts.

1. Clean the surface of the concrete, clean concrete dust and debris out of the crack by sand blasting, air-water jet, or both, and remove standing water.

2. Install grout ports at intervals along the crack to provide a pressure tight contact with the injection apparatus. Grout ports may be installed on built-up seats or in holes drilled at a 45-degree angle into the crack. These holes should be one half inch in diameter and should connect with the crack in the lower half of the crack. Spacing of grout ports should be no more than the thickness of the culvert wall.

3. Seal the crack with a cement paint, sealant, or grout.

4. After the seal has dried and set, flush the crack to clean it and to test the seal, but make sure that no standing water remains in the crack.

5. Grout the crack. The grout mixture may contain cement and water for narrow cracks, or cement plus sand plus water for wider cracks. However, the water cement ratio should be kept as low as possible to provide maximum strength and low shrinkage. The grout may include a water reducer or other admixture to improve the properties of the grout. For example, an expansive cement grout may be appropriate.

1.2.3 Repair by injection of epoxy adhesive.

Epoxy adhesive consists of two components, stored in separate reservoirs, and mixed just before injection into the crack. The equipment used to measure and mix the two injection adhesive components and inject the mixed adhesive into the crack should consist of portable pumps which provide in-line metering for positive control of the two components at the nozzle(s). The required volume ratio for the components should be maintained with a tolerance of plus or minus 5 percent by volume at any discharge pressure. Automatic pressure control should be capable of discharging the mixed adhesive at any pre-set pressure with an accuracy of plus or minus 5 psi. A manual pressure control device should also be provided. The injection machinery should be equipped to ensure that the machine will automatically be turned off when one of the reservoirs is empty and only one component is being pumped. Epoxy materials and application should be in accordance with California Department of Transportation Standard Specifications (Section 95).

1. Clean cracks and surfaces adjacent to cracks of dirt, dust, grease, oil, efflorescence or other foreign matter detrimental to bond of the epoxy injection surface seal system. Acids and corrosives should not be used for cleaning.

2. Provide entry ports along the crack at intervals of not less than the thickness of concrete at that location.

3. Apply surface seal material to the face of the crack between the entry ports. For through cracks, surface seal should be applied to both faces, if possible.

4. The surface seal material must be allowed to gain adequate strength before proceeding with the injection.

5. Begin injection of epoxy adhesive at the lower entry port and continue until epoxy adhesive appears at the entry port adjacent to that being pumped.

6. When epoxy adhesive appears at the next port, discontinue injection at the entry port being pumped, and being epoxy injection at the port where epoxy adhesive has appeared.

7. Perform epoxy adhesive injection continuously until cracks are completely filled.

8. If port to port travel of epoxy adhesive is not achieved, the work should immediately be stopped and the spacing of the ports reduced or grout modified.

9. When cracks are completely filled allow epoxy adhesive to cure for a sufficient time to allow removal of surface seal without any draining or runback of epoxy material from cracks.

10. Surface seal material and injection adhesive runs or spills should be removed from concrete surfaces.

11. Finish the face of the crack flush to the adjacent concrete and remove all indentations or protrusions caused by the placement of entry ports.

1.3 JOINT REPAIR

Application:

All prefabricated and jointed culverts.

Definition:

Joint sealing is the installation of an expansion ring gasket and a band. Voids in soil behind the culvert are pressure grouted (see Section 1.4).

Alternative materials:

- Corrugated band with sleeve, strip, or mastic gasket.
- Universal band with sleeve, strip, or mastic gasket.
- Semi-corrugated band with O-ring or mastic gasket.
- Channel band with mastic gasket.
- Flat band with O-ring, sleeve, strip, or mastic gasket.
- Wing channel band with mastic gasket.
- Proprietary rubber seals.

Note: The selection of type of band depends on the pipe materials, the amount and nature of separation, and the extent of misalignment.

Alternative methods:

- Steel expansion ring gasket.
- AMEX-10/WEKO-SEAL Joint sealing system.
  TM Internal (Miller Pipeline Corporation, Indiana).
- Cherne air test and grouting system.

Alternatives to joint sealing:

Slip lining; crack sealing methods (for concrete culverts); flexible tube lining; cement mortar lining; replacement.

Advantages of joint sealing:

- Low cost
- Fairly low resource commitment
- Prevents further deterioration due to infiltration or exfiltration of backfill material

Disadvantages of joint sealing:

More complex than crack sealing for concrete culverts

Possible problems or difficulties:

- Closure ring may have to carry structural loads and/or hydraulic pressure
- Joints may be difficult to clean

Criteria for use of joint sealing:

- Width of joint separation
- Evidence of infiltration or exfiltration
- Extent of other joint defects, such as spalling in concrete culverts
- Extent of other damage to culvert, such as distortion of metal culvert
- Desired future life of culvert

Sources of Information:

- Federal Highway Administration, for steel expansion ring

gaskets (Ref. 4)

- Miller Pipeline Corporation, for joint sealing systems - Amex-10/WEKO SEAL (Ref. 23)

- Minnesota Department of Transportation (Ref. 11)

- Indiana Department of Transportation, for joint sealing by chemical grouting (Ref. 10)

Construction Methods

The following two alternative procedures apply to sealing the joints of corrugated metal and precast concrete culverts. Although the methods are used more commonly for metal (flexible) culverts, they may be used for other types of culverts, with some adaptations.

1.3.1 Steel expansion rings and gaskets.

Several types of corrugated steel expansion rings are available for repair of culvert joints from inside of the culvert.

1. Select an appropriate band. The type and width of band to be used is determined based on the amount of separation and the misalignment at the joint. For example, a corrugated band would be selected if there were no or very little misalignment.

2. Select a gasket that will properly seal the joint. This will depend on the type and width of the band to be used. For example, an O-ring type, or closed cell sponge strip type, could be used with other types of bands where minor misalignment is determined; and a mastic type could be used with a flat band where misalignment is greater. Strip type

gaskets should be wider than the band.

3. Fabricate band(s) using two sections that conform to the existing pipe shape. Each section should conform as nearly as possible to one half of the cross section of the pipe. Shorter than one half cross section may be desirable if the two pieces are to be bolted together prior to placement at the point. Size and location of angles are determined by design, space required for hardware (nuts and washers), and space required to facilitate installation. The size of the bolt should be 1/2 inch minimum. It may be necessary to specify larger diameter bolts for some installations.

4. Divert flow away from the culvert.

5. Clean and prepare the peripheral area of the pipe where the band is to be placed. Dirt and debris should be removed. For metal culverts, localized dents and distortions should be smoothed out by hammering with heat applied as necessary to help in the straightening. All fins, burrs, and other imperfections in the pipe should be ground to a smooth surface.

6. Install the band and gasket, either with the two sections bolted together or as separate units. The bottom half should be installed first. On larger pipes, the top half may require temporary support prior to bolting the sections together. If a strip gasket is used, the lap should be as close to the top as practical. On pipe arches, it may be necessary to weld the bottom section to the pipe due to the possibility of buckling at the invert when the bolts are tightened.

7. Tighten the bolts evenly until a tight fit is realized. A tight fit may be determined by the compression of the gasket

or band-to-pipe contact. Caution: Observe invert area of band for buckling, especially with pipe-arch conduits.

8. Seal the longitudinal band overlap with a mastic.

1.3.2 Internal joint-sealing system.

These systems use proprietary seals. The work is performed by specialty contractors.

1. Clean the culvert in the area of the joints to be sealed. Gaps in the joints must be cleared of dust and debris.

2. Fill gaps in joints with a quick-setting mortar or grout until the surface is flush with the internal surface of the culvert.

3. Prepare the area of the culvert on both sides of the joint, where the "lip seals" will make contact with the culvert. The finish should allow the "lip seals" to bed consistently so as to provide a permanent seal.

4. Just before fitting the seal, clean the area and coat with a joint lubricant.

5. Place the seal in position.

6. Place two stainless steel rounded edge shims under the wedge area in grooves in the rubber seal and install the stainless steel bands in the grooves.

7. Attach the hydraulic jack expander to expand the stainless steel bands and the rubber gasket against the inside of the culvert. After the gasket ring is expanded set the wedge shims between the ends of the bands and retract the expander.

1.4 GROUTING VOIDS IN SOIL ENVELOPE

Application:

Any type of culvert with voids in backfill or in base material under culvert.

Definition:

External grouting is the introduction of a portland cement based grout (possibly with special admixtures including polymer resins) into the voids behind or beneath a culvert. Grouting may be accomplished through the inside of the culvert through prepared grout holes in the culvert wall or from grout tubes drilled through the fill.

Alternative materials:

- Portland cement based grout or mortar (with or without admixtures)
- Chemicals and foaming grouts (for conditions requiring resistance to high fluid pressures)

Note: The material should not shrink, segregate, or otherwise create additional problems. Portland cement based grout is adequate for most culvert grouting.

Alternative methods:

- Gravity flow from above the void.
- Gravity flow through a tremie pipe or tube (from bottom up)
- Pressure grouting

Alternatives to external grouting:

Replacement

Advantages of external grouting:

- Prevents distortion or collapse of culvert
- Low cost

Disadvantages of grouting:

Difficult to judge completeness of repair

Difficulties and precautions:

- Air entrapment must be avoided.
- Grout introduced by gravity feed, into a void filled with water, may disperse in the water - it is preferable that water be removed first, if possible.
- Chemical grouts should only be used in cohesionless soil.

Criteria for external grouting:

Presence of voids that threaten the integrity of the culvert.

Safety precautions:

Grouting pressure should be carefully monitored to prevent bursting of lines or displacement of culvert walls.

Sources of information:

- Federal Highway Administration (Ref. 4)

- Pressure Grout Company, for grouting (Ref. 29)

- GKN Hayward Baker, for grouting (Ref. 20)

Construction Methods

There are three alternative procedures for grouting voids behind the culvert. The decision to inject the grout from inside or outside the culvert is normally determined by the grout contractor based on site conditions and experience.

1.4.1 Gravity flow from above the void.

This method involves pouring the grout into the void from above. It is assumed that the fluid grout will completely fill the void without entrapping air. Any water in the void should be pumped out prior to grouting.

1.4.2 Grouting through a tremie pipe or tube.

A tremie pipe or tube may be warranted for some site conditions where there is a potential problem of entrapment of air in the grout. For this gravity feed method the grout is introduced into the void by pouring it into a tremie tube inserted at the bottom of the void, so that grout fills the void from the bottom with an upward flow of the grout.

1.4.3 Pressure grouting.

This is the method that is most commonly used to fill voids behind the culverts. If the void is behind an open joint the joint should first be sealed from within the culvert with a concrete mortar, or a joint sealing system.

The most effective procedure for pressure grouting involves installation of grout tubes at the bottom and top of the void. The grout is then pumped into the lower tube. Pressure should be

just sufficient to move the grout, and pressure must be monitored so that the operation can be stopped if the pressure builds up because of a blockage in the pipes. Air or water will at first flow out of the upper tube, then a water grout will flow out, and finally a pure grout will flow out of the upper tube. At this point the void can be considered to be properly filled.

1.5 CORRUGATED METAL STRUCTURAL PLATE SEAM REPAIR

Application:

Corrugated Metal Structural Plate Culverts.

Definition:

Longitudinal seams in corrugated metal structural plate culverts are repaired by splicing, rebolting or welding.

Alternative materials:

- Reinforcing steel - welded
- Shotcrete beam - anchored by U-brackets

Alternative methods:

- Repair with reinforcing bars welded to the inside corrugation valleys at location of seam distress.
- Repair with steel fibre reinforced shotcrete beam (with silica fume admixture)

Alternatives to seam repair:

Slip lining; flexible tube lining; cement mortar lining; replacement.

Advantages of seam repair:

- Fairly low cost
- Fairly low resource commitment
- May prevent development of an unstable condition

Disadvantages of seam repair:

Will not correct an unstable soil envelope condition

Criteria for seam repair:

- Extent of cracked seams
- Stability of culvert

Safety precautions:

Caution should be used when welding galvanized metals because fumes can be toxic. Galvanizing should be removed by grinding or a combination of heat and grinding prior to welding, and welder should wear a mask in case any galvanizing remains in the area being welded.

Sources of information:

- Federal Highway Administration, for repairs with reinforcing bars (Ref. 4)

- Alberta Transportation and Utilities, for repair with a shotcrete beam (Ref. 14)

Construction Methods

The following procedures may be used for repairing cracked longitudinal seams in corrugated metal structural plate culverts over three feet in diameter or height.

1.5.1. Repairs with reinforcing bars.

The following procedure is used to repair cracks in seams through bolt holes. This procedure involves welding #5 reinforcing bars across the seam. The method is economical and relatively easy to use.

1. Establish the required length of the reinforcing bar. The splice should extend six inches on either side of the seam. A dye penetrant may be useful to determine the crack length. If there is any doubt the total length of the plate should be repaired.

2. If the damaged seam is below water level divert flow away from the culvert.

3. Clean the area to be repaired. Remove the galvanizing in the area where the reinforcing bar will be welded to the plate. Removal of galvanizing can be done by grinding or a combination of heating and grinding.

4. Place the reinforcing bar where good contact is made to plates on each side of the joint. The placement will normally fall between the peak and valley of the corrugations. See Figure 1.5.1.

5. Tack weld the bars to both plates. Complete the weld on the side of the bar to near the peak of the bar. Welds should be approximately one inch long and spaced approximately two inches apart. These dimensions may be adjusted to obtain good contact between plate and bar. Excessive amounts of welding must be avoided on relatively thin plates (0.105 inch to 0.276 inch) to avoid distortion and/or puncture due to heat.

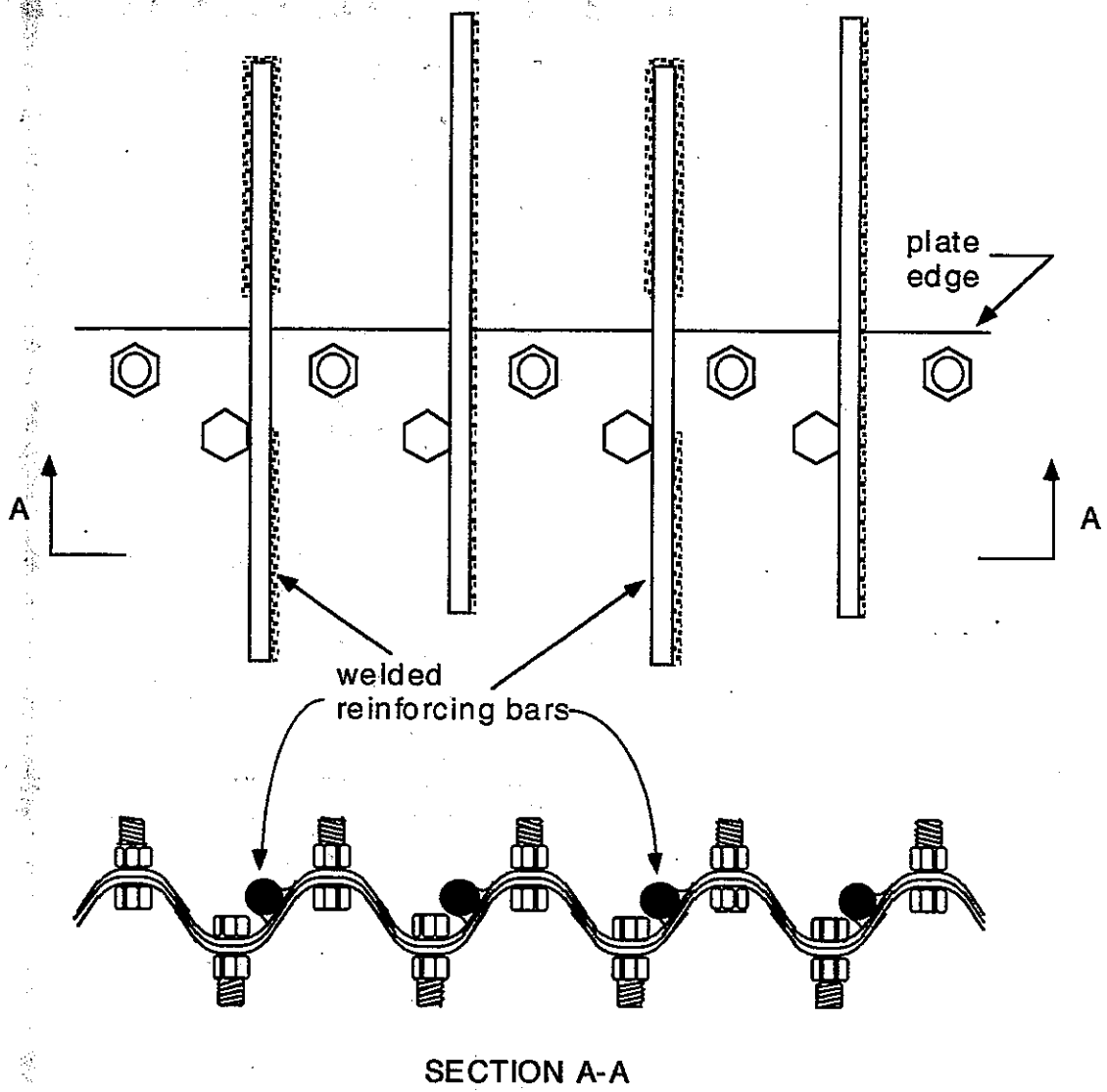


Figure 1.5.1 METAL CULVERT PLATE SEAM REPAIR WITH REINFORCING BARS

6. The end of the crack may be drilled out to prevent further propagation.

1.5.2 Repair with a shotcrete beam.

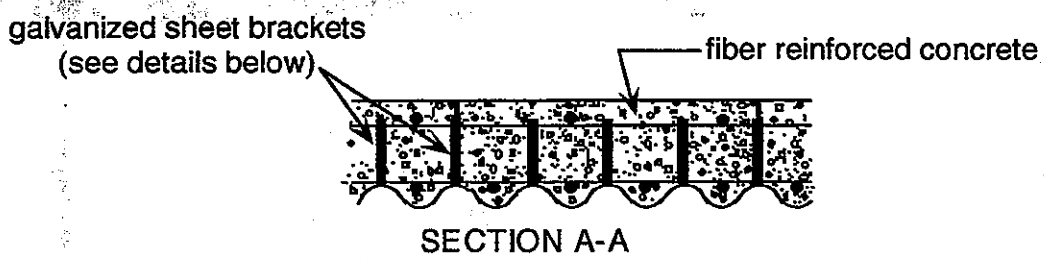
1. Connect steel brackets to the structural plate corrugated steel pipe (SPCSP) plates. The U-shaped galvanized steel brackets, approximately 2.7 mm thick, are attached to the SPCSP plates using Hilti pins (powder actuater fastener). The variation in plate thickness of the SPCSP requires careful selection of Hilti pins, driving guns, and cartridges. Recommendations, based on experience (Ref. 14) are:

Plate thickness	Hilti Gun	Pins	Cartridges
4 mm	DX 450	ENK 19S12	Red
4.3 mm	DX 650	ENP 3-21-L15	Yellow
5.0 mm	DX 650	ENP 3-21-L15	Red

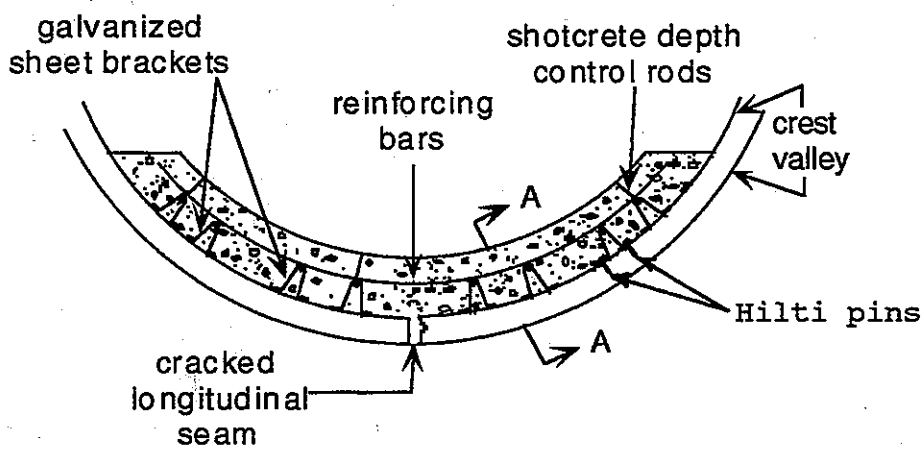
The brackets may be pinned along the centerline of the inside crest of the corrugation (see Figure 1.5.2) or pinned to the tangent portion of the corrugation (see Figure 1.5.3). Pinning to the troughs provides higher rigidity against the driving energy of the gun, which helps avoid loose connections on thinner plates. Pinning to the crests has the advantage of placing Hilti pins in a shear mode rather than a "pulling out" mode, which results in stronger connections on all plate thicknesses.

2. Prepare SPCSP plates by lightly sand blasting to provide a textured rough surface without removing the zinc coating.

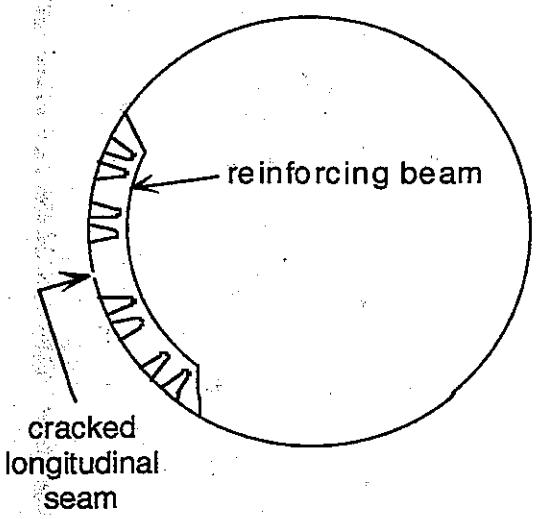
3. Divert steam flow away from the culvert.



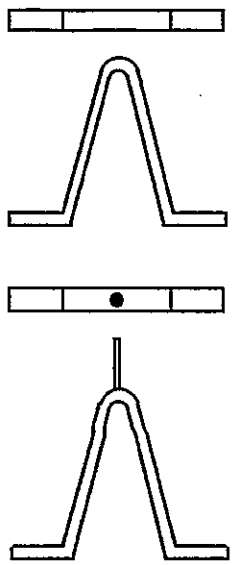
SECTION A-A



DETAIL OF REINFORCING BEAM

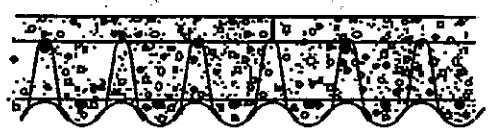


CROSS SECTION OF CULVERT

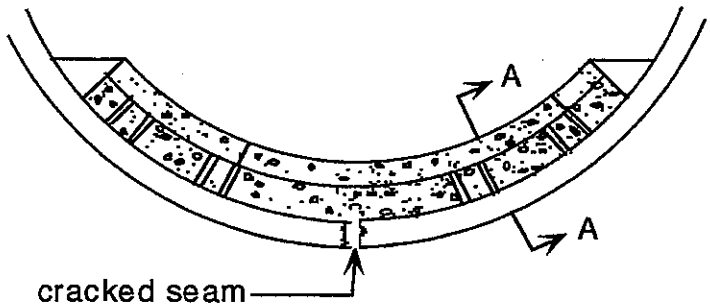


DETAILS OF U - BRACKETS

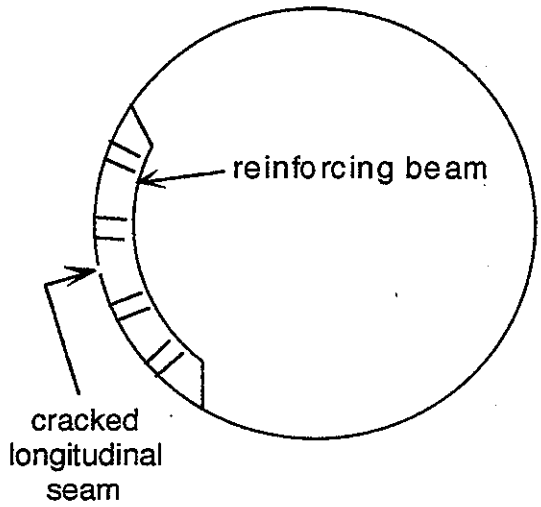
Figure 1.5.2 REPAIR OF METAL PLATE SEAMS WITH REINFORCED SHOTCRETE BEAM WITH BRACKETS PINNED ALONG THE CENTERLINE OF THE INSIDE CREST



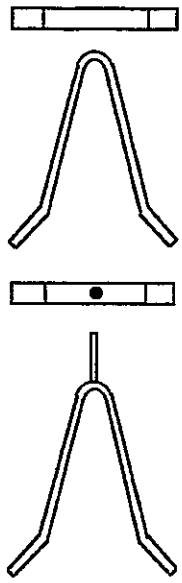
SECTION A-A



DETAIL OF REINFORCING BEAM



CROSS SECTION OF CULVERT



DETAILS OF U - BRACKETS

Figure 1.5.3 REPAIR OF METAL PLATE SEAMS WITH REINFORCED SHOTCRETE BEAM WITH BRACKETS PINNED TO THE TANGENT PORTION OF THE CORRUGATION

4. Immediately before shotcreting, wash the plates with an air-jet.

5. The shotcrete used above to construct the bedding for the plates should consist of a 9000+ psi compressive strength steel fiber reinforced mix. A silica fume admixture may be used to reduce rebound losses. The minimum temperature of the shotcrete mix should be 15°C (59°F) during shooting, and the minimum bond surface temperature should be 5°C (41°F). If necessary, the plates and the shotcrete mix should be heated to achieve these temperatures.

6. Apply a slurry coat to the area receiving the shotcrete. Two rough coats of shotcrete should be applied, allowing one hour set time for each coat, to provide a minimum thickness of 100 mm. After about an hour and a half of set time the finish coat should be applied to establish the designed thickness and curvature.

7. Thickness control may be monitored by using three rows of depth gauges located at top, middle and bottom of the beam, and at 1.5 meter intervals along the longitudinal axis of the culvert.

1.6 MASONRY CULVERT WALLS REPAIR

Application:

Masonry culverts.

Definition:

Repair of masonry culvert walls consists of replacing mortar and stones to restore the wall to a durable condition.

Alternative materials:

Cement mortar and stone

Alternative methods:

- Standard stone masonry procedures
- Relining (steel liner plate) or flexible tube lining

Alternative to masonry repair:

Replacement

Advantages of masonry repair:

Low cost

Difficulties and precautions:

- Surface should be kept wet during repairs and for three days after completion.
- Work should not be performed in freezing weather.

Criteria for masonry repair:

Extent of deterioration

Source of information:

Federal Highway Administration (Ref. 4)

Construction Methods

1. If the damaged area is below water level divert flow away from the culvert.

2. Prior to any restoration work or remortaring or replacement of stone, all limbs, vines, roots, or other organic material should be completely removed from the masonry wall, at least in the vicinity of the repair zone.

3. All loose soil, loose stones, loose mortar, organic or other foreign material should be removed to a depth of six inches from the face of the wall. Removal to a depth beyond six inches would require replacement with compacted mortar or a combination of stone and compacted mortar.

4. Existing joints should be cleared by water jetting, but care should be taken to avoid excessive removal of existing material.

5. The voided areas should be wetted and surface dried, and repaired by a mortar filling to within one-half inch of the original surface.

6. Mortar should be of a stiff consistency (essentially zero slump) and should be ram packed into voids and joints.

7. In areas of large voids, replacement stones may be used in addition to mortar. Stone should match the wall being repaired and should be sound and durable. The stone should be free from seams, cracks, structural defects, and imperfections tending to reduce its resistance to weathering. It should also be free from rounded, worn or weathered surfaces.

   In general, stones should have a thickness of not less than six inches. Widths should not be less than 1-1/2 times thicknesses and lengths not less than 1-1/2 times their widths.

8. The masonry should be kept wet while repairs are being performed. The repaired surfaces should be protected from the sun and kept wet for a period of three days after completion of the work for proper curing. Mortaring should not be performed in freezing weather. Any work damaged by frost should be removed and replaced.

1.7 INVERT PAVING WITH CONCRETE

Application:

Any type of culvert.

Definition:

Paving refers to covering the invert with a layer of concrete. Generally the lower quadrant is paved. If the invert is seriously damaged this must be considered to be a structural repair.

Alternative paving materials:

- Conventional portland cement concrete.
- Welded wire mesh reinforced concrete
- Steel fibre reinforced concrete (does not improve resistance to sand abrasion but good for resisting impact related damage).
- High strength concrete.
- High early strength concrete (shrinkage may be high).
- Latex modified or low slump concrete.

Alternative coating materials:

- Epoxy resin
- Polymer concrete

Alternative methods:

Clean area, divert flow, attach anchors and reinforcement, place concrete.

Note: Method for anchoring paving to culvert is different for different types of culvert materials.

Alternatives to paving with concrete:

Slip lining; flexible tube lining; cement mortar lining; replacement.

Advantages of paving with concrete:

- Prolongs life of culvert
- Fairly low cost
- Medium resource commitment
- High strength concrete provides resistance to abrasion
- Concrete paving with polymer coating provides resistance to acid

Disadvantages of paving with concrete:

Subject to corrosion if runoff is acidic.

Difficulties and precautions:

- Pipe surface should be clean and dry
- If reinforcement may be subjected to corrosion, coat surfaces with epoxy immediately prior to placing concrete

Criteria for use of invert paving:

- Extent of damage
- Condition of central portion of culvert barrel
- Type of abrasion (not suitable for rock abrasion)

Sources of information:

- California Department of Transportation, for paving with plain Portland cement concrete (Ref. 9)
- National Corrugated Steel Pipe Association (Ref. 24)
- Ohio Department of Transportation, for paving with wire mesh, reinforced concrete (Ref. 25)
- State of Colorado, for paving with high strength concrete (Ref. 18)
- American Concrete Institute (ACI) Committee 363 (Ref. 16)

Construction Methods

Invert paving may be installed in all types of culverts over three feet in diameter or height; however, different methods will need to be used for anchoring the concrete to the existing culvert. The paving material should be in accordance with the California Department of Transportation Standard Specifications (Section 90-10). High-strength concrete or high early strength concrete may be used if appropriate.

Site preparation:

1. Divert flow away from the culvert prior to the start of the repair work.

2. Clean away all grease, dirt, scale, loose materials and other foreign materials and prepare the invert for placement of the paving. If the culvert had been paved previously, the previous paving or protective layers should also be properly cleaned and prepared.

3. In case of corrugated metal culverts, severely deteriorated metal plates must be replaced by new metal plates, so that the culvert will have structural strength to resist lateral thrust loading. The thickness of the new plates must be at least that of the original metal culvert.

4. Any unsuitable material below the bottom of the existing culvert should be removed and replaced by concrete or approved structural material.

5. All voids below the bottom of the existing culvert should be filled in with concrete or approved grout.

Procedure:

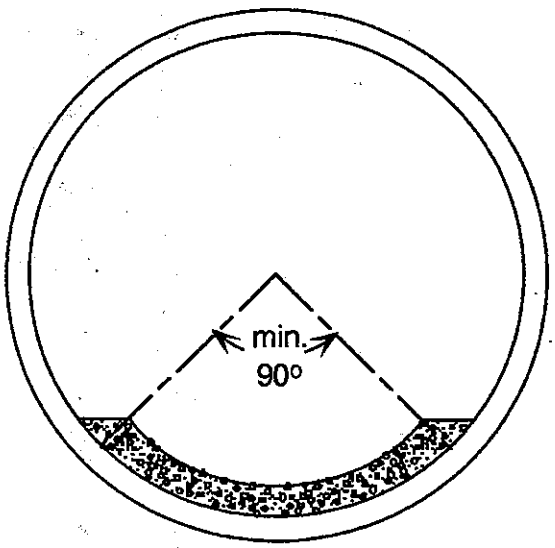
Material for invert paving may be conventional Portland cement concrete, high early strength concrete, or high strength concrete, and the concrete may be reinforced by welded wire mesh or by steel fibers. The paving should cover at least the bottom quadrant of the inside circumference of the pipe.

1.7.1 Paving metal culverts with unreinforced or fiber reinforced concrete.

1. Dry the surface to be paved.

2. Place the concrete pavement in accordance with California Department of Transportation Standard Specifications (Section 51-1.09) conforming to the radius of the pipe.

3. The minimum coverage over corrugations of corrugated metal pipes should be two inches for unreinforced concrete or one and a half inches for reinforced concrete. See Figure 1.7.1.



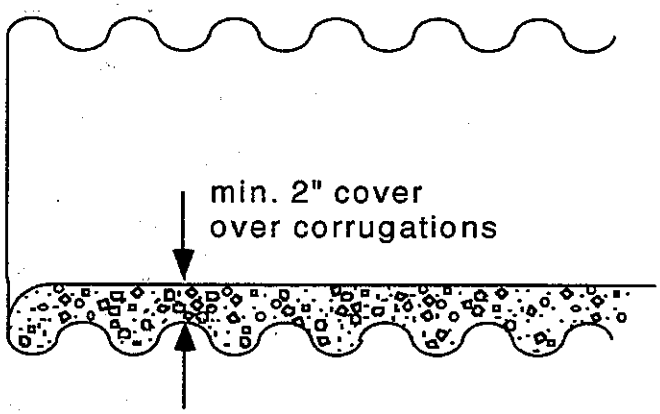


Figure 1.7.1 INVERT PAVING METAL CULVERTS WITH UNREINFORCED CONCRETE

4. The paved invert should extend the full length of the culvert for an arc of no less than 90°.

5. The pavement should be finished to a smooth surface.

6. Immediately after completion of finishing, the surface should be protected by either an approved curing cover or an approved membrane curing compound in accordance with California Department of Transportation Standard Specifications (Section 90-7).

7. If service requirements permit, the concrete should be cured for a minimum period of 48 hours before water is permitted to flow on the invert.

1.7.2 Paving metal culverts with welded wire mesh reinforced concrete.

1. Dry the surface to be paved.

2. Place the welded wire mesh reinforcement on the invert. The wire mesh reinforcement may be placed directly on the corrugation and tack welded to the invert every 30 inches along the pipe and every two inches across the pipe. Transverse wires should line up with grooves of the corrugations. Alternatively the wire mesh reinforcement may be placed two inches above the crests of corrugations and fasten securely by welding or tying to studs or angles previously welded to the structure. Studs and angles should be placed two feet on center longitudinally and transversely. The reinforcement should be placed to provide a four-inch minimum clearance from the edges of the concrete and should taper off six inches minimum. Unless other-wise shown on the plans, the steel welded wire mesh (also known as WWF - welded wire fabric) reinforcement may consist of #10 gauge wire at

six-inch centers transversely and longitudinally. See Figure 1.7.2.

3. Place the concrete pavement by conventional method to provide at least two inches of cover over the mesh reinforcement and finish as detailed above.

4. The paved invert should extend the full length of the culvert for an arc of no less than 90°.

1.7.3 Paving concrete culverts.

The procedures are similar to those for metal culverts except that the wire mesh reinforcement, if used, cannot be welded to the culvert. The invert paving may be anchored to the existing structure by #4 steel reinforcing anchor bars at 24-inch on center. The anchor bars should be grouted, into two-inch diameter holes drilled in the concrete to a depth of one half the wall thickness, at least 36 hours prior to placement of the concrete paving. The concrete surface that receives the paving should first be saturated and surface dried to allow for a strong bond between the paving material and the concrete. The paved invert should extend the full length of the culvert for an arc of 90° or four inches beyond each side of eroded surface, whichever is greater.

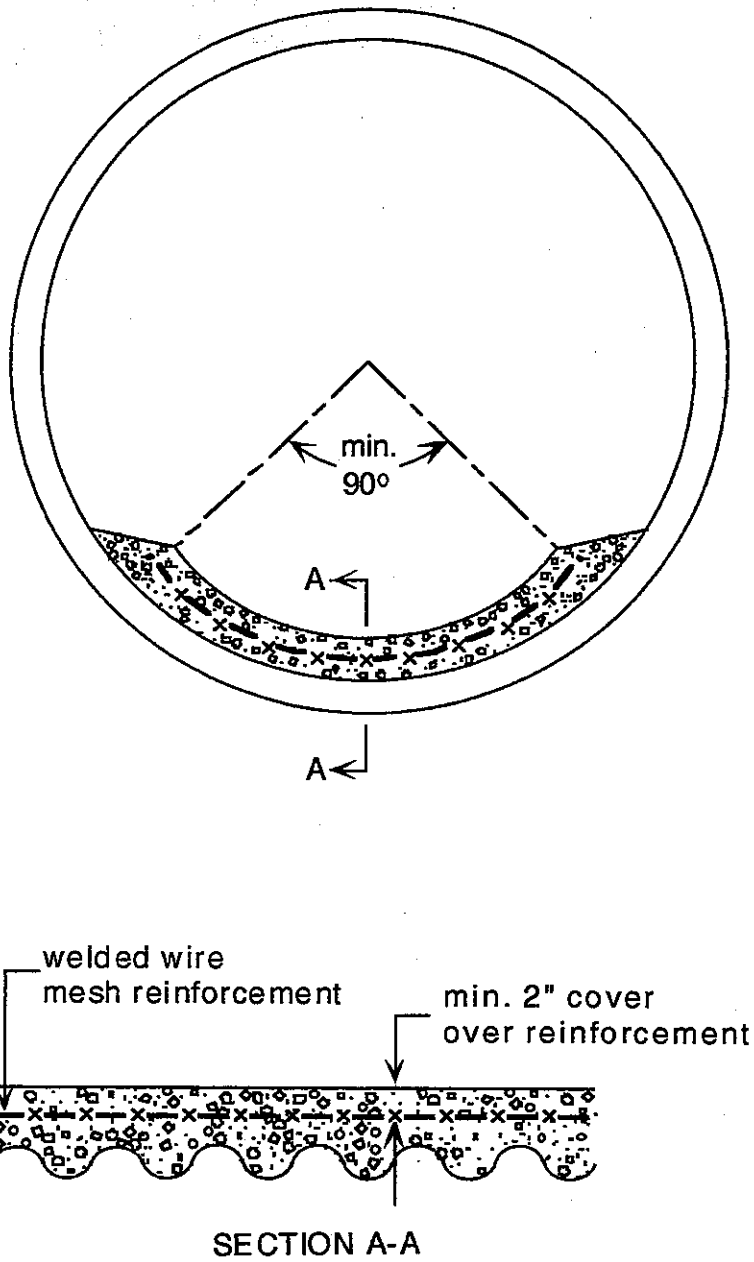


Figure 1.7.2 INVERT PAVING METAL CULVERTS WITH REINFORCED CONCRETE

1.8 INVERT PAVING WITH SHOTCRETE OR GUNITE

Application:

All types of culverts.

Definition:

Shotcrete paving refers to the pneumatic transportation and placement of portland cement based mortar or concrete in the pipe invert. (Gunite refers to a dry mix shotcrete.)

Alternative materials:

Portland cement based mortar or concrete.

Alternative methods:

Pneumatic transportation and placement.

Alternatives to invert paving with gunite:

- Invert paving with concrete.
- Replacement; slip lining; flexible tube lining; cement mortar lining.

Advantages of paving with shotcrete:

- No formwork needed
- Structurally sound and durable (if properly applied)

Disadvantages of paving with shotcrete:

- Subject to corrosion if runoff is acidic.

Difficulties and precautions:

- Surface must be properly prepared.
- Surface must be predampened but free of standing water.

Criteria for using shotcrete invert paving:

- Extent of damage
- Condition of central portion of culvert barrel
- Type of abrasion (not suitable for rock abrasion)

Safety precautions:

- Inspect hoses frequently
- Be aware that hoses may burst
- Provide noise protection to workers
- Use masks to avoid breathing cement dust

Sources of information:

- Federal Highway Administration (Ref. 4)
- Indiana Department of Transportation (Ref. 10)
- American Concrete Institute (Ref. 16)
- California Department of Transportation Standard Specifications, Section 53 (Ref. 17)

Construction Methods

The term shotcrete or gunite refers to the process of pneumatically transporting and placing portland cement-based mortar or concrete with compressed air. The term gunite frequently refers to a dry mix, whereas shotcrete may refer to both wet and dry mixes. Materials and mix design should conform to the California Department of Transportation Standard Specifications (Sections 53-1.02 to 53-1.06).

Site Preparation:

1. Prepare the work area properly for the application of either dry or wet shotcrete mixes.

2. Steel surfaces of the culvert should be cleaned of loose mill scale, rust, oil, paint or other contaminants.

3. For concrete surfaces, it is imperative to completely remove all spalled, severely cracked, deteriorated, loose or otherwise unsound concrete by chipping, scarifying, sandblasting, waterblasting, or other mechanical means. For solid concrete surfaces it may be necessary to sandblast or otherwise remove the surface layer of cement paste to facilitate bond between the existing concrete and the shotcrete.

Procedure:

1. Prepare the interior surface of the pipe for reinforcing steel.

2. Steel reinforcement, consisting of welded wire mesh fabric (#10 wires at six-inch on center), or deformed reinforcing bars, must be installed if the shotcrete will carry structural

loads or if drying shrinkage cracking must be avoided.

3. The reinforcement should be rigidly secured in position with anchorage devices, or #4 dowels at 24-inch on center in two-inch diameter holes of depth of one half the wall thickness, to assure structural interaction of the shotcrete with the existing structure.

4. Earth, concrete, and masonry surfaces should be saturated and surface dried so as to minimize the creation of weak interface bonds by the absorption of water from the shotcrete.

5. The shotcrete should be mixed, pneumatically transported, and placed in accordance with recommendations and guidelines contained in the standard specifications.

6. Shotcrete should be applied behind the reinforcement before it accumulates on it.

7. If multiple layers of reinforcement are used, one layer of reinforcement should be covered with shotcrete per application.

8. Shotcrete cover of the reinforcement should be a minimum of 2 inches.

9. The paved invert should extend the full length of the culvert for an arc of 90° or four inches beyond each side of the eroded surface, whichever is greater.

10. Finish may be applied to the surface with gun, broom, float, trowel, or etc.

11. Immediately after finishing, shotcrete should be kept continuously moist for at least 24 hours by using (a)

sprinkling; (b) an absorptive mat, fabric, or other covering; or (c) a curing compound. If service requirements permit, the total curing time should be 7 days. The temperature must be maintained above 40 degrees. Curing time may be reduced if high early strength cement is used.

1.9 INVERT PLATING

Application:

All types of culverts.

Definition:

The invert of the culvert is armored with steel plates to minimize abrasion or impact damage.

Alternative materials:

- Steel plates (3/8 to 2 inches thick)
- Double thickness of pipe (when installed)
- Steel and bridge decking or old railroad rails
- W or thrie beams from old guard rails

Alternative methods:

- Plate on four-inch bed of concrete mortar in corrugated pipe culvert (mortar placed after plates are in place).
- Plate laid on box culvert invert and bolted through culvert to bedrock.

Alternatives to invert plating:

Concrete paving (except when severe rock abrasion is present); replacement; slip lining; flexible tube lining; cement mortar lining.

Advantages of invert plating:

- Fairly low cost
- Medium resource commitment
- Provides resistance to rock abrasion
- Prolongs life of culvert (20+ years)

Difficulties and precautions:

Lifting steel plates into position

Criteria for using invert plating:

Rock abrasion

Sources of information:

- Alabama Highway Department 1952, for armoring corrugated metal pipe inverts with steel plates (Ref. 13)

- Colorado Highway Department, for armoring concrete box culverts with steel plates (Ref. 18)

- Oregon Highway Department, for armoring concrete box culverts with steel grid bridge decking and old railroad rails (Ref. 26)

- California Department of Transportation, for paving with guard rails (Ref. 6)

Construction Methods

Armoring the inverts of culverts with steel plates to prevent or minimize abrasion and impact damage has application to both concrete and metal culverts. Somewhat different methods will be

needed for anchoring the steel plates to concrete and to steel surfaces.

1.9.1 Invert plating for corrugated metal culverts.

1. Water should be diverted away from the culvert during construction.

2. Check for the cracks in the pipe walls through which groundwater may enter into the culvert. Seal these cracks with a quick-setting grout. (See crack sealing pg. 40.)

3. After all water is removed from the culvert, attach anchor studs to the invert and to the steel plates. See Figure 1.9.1.

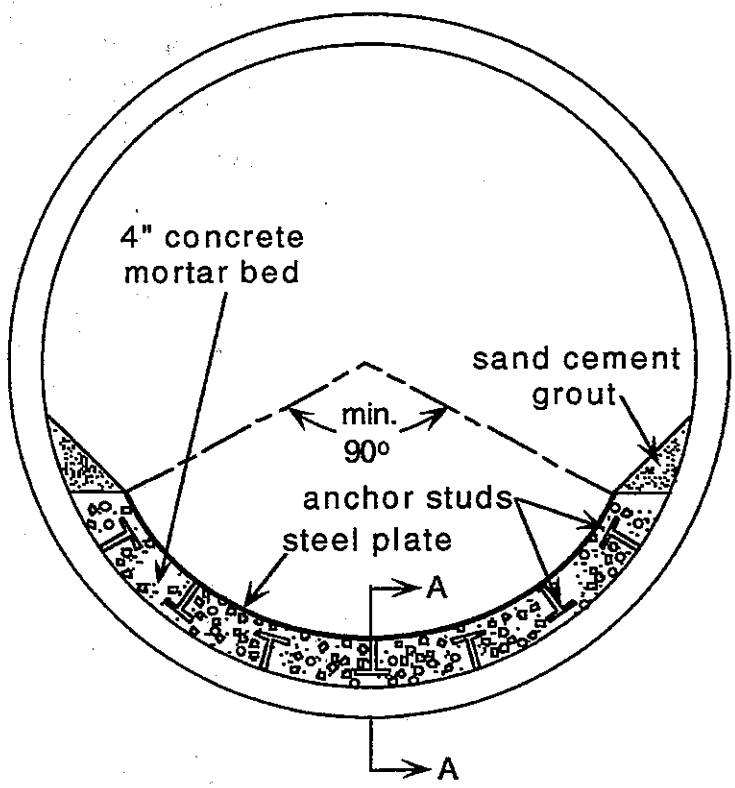
4. Set a group of three plates on the invert surface, tack-weld them together and brace.

5. The plated invert should extend the full length of the culvert for an arc of 90° or four inches beyond each side of the eroded surface, whichever is greater.

6. Place the concrete bedding below the liner plates. The concrete may be vibrated to remove the larger air voids.

7. After allowing the concrete to cure for seven days, remove the braces and weld the plates together. Gaps between the plates which may be caused by variations in alignment and profile, should be closed by welding on strips of armor plate.

8. The edges of the unfinished concrete should be coated with an epoxy and a sand-cement grout should be applied to provide a uniform finish.



SECTION A-A

Figure 1.9.1 INVERT PLATING METAL CULVERT

1.9.2 Invert plating for concrete culverts.

1. Water should be diverted away from the culvert during construction.

2. Check for the cracks in the pipe walls through which groundwater may enter into the culvert. Seal these cracks with a quick-setting grout. (See crack sealing pg. 40.)

3. Pave the invert with concrete to the desired shape for bedding the steel plates. Allow the concrete to cure.

4. Position the steel plates across the invert.

5. Drill holes in the culvert through the existing holes in the plate. The holes should pass through the concrete and into the bedrock.

6. Anchor the plates to the bedrock with bolts set into an epoxy resin.

1.10 INVERT COATING

Application:

All metallic pipe culverts. (Cast iron, steel and corrugated pipe culverts.)

Definition:

Invert coating is the application of a hot single component thermoplastic modified bituminous material on the inside of metallic culverts.

Alternative materials:

- Oxidized (airblown) asphalts
- Polymers (ethylene acrylic acid film)
- Polymerized asphalt - under development (Ref. 27)
- Mastic asphalt
- Epoxy

Alternative methods:

- Spray application
- Mopping (application by brush or mop)

Alternatives to invert coating:

Mortar lining, slip lining; flexible tube lining; replacement

Advantages of invert coating:

Bituminous coating bonds strongly to the metal surface and

provides protection against corrosion.

Disadvantages of invert coating:

- In dry structure fire danger exists
- Bond between culvert and invert paving may fail
- Does not withstand abrasion

Difficulties and precautions:

- The liquid material should be heated using indirect heating methods.
- During storage, the liquid material should be periodically recirculated using pumps, or stirred.
- Hot bulk storage temperatures should not exceed 350°F or exceed 10 days.
- Metal surface must be clean and dry

Criteria for use of invert coating:

- Extent of corrosion and abrasion
- Stability of culvert

Safety precautions:

- The application material should not be heated by direct flame, which may cause fire in the material due to its flammable property.

- Coating material should not produce toxic fumes during and after application, and the product must have been tested for safety prior to its use. Special precaution should be used when materials are being applied in close quarter situations because even materials with low toxicity can create problems under these conditions.

Environmental considerations:

The California Department of Fish and Game has raised as an issue possible environmental hazards associated with the use of some asphalt coating.

Source of information:

- Pacific Corrugated Pipe Co. (Ref. 27)
- Asphalt Institute (Ref. 15)

Construction Methods

Damaged culvert inverts may be coated with various materials which are generally applied by heating the material and spraying it onto the invert. Materials should conform to standard specifications and all necessary precautions to protect workers and the environment should be taken.

Site preparation:

1. The existing culvert must be cleaned and dried before it is coated. All dirt, scale, loose and foreign material should be removed.

2. Cleaning may involve high pressure water or water jets and rotary cleaning equipment.

3. Larger diameter culverts may normally be cleaned by workmen with hand tools.

4. Water flow through the culvert should be completely diverted.

5. Patch work should be done if necessary.

Procedure:

1. The coating material should be heated using indirect heating methods. Direct heating may ignite the coating material which is usually highly inflammable.

2. Liquid coating material may be stored in tanks which are oil, steam or electrically heated.

3. The material should be heated to manufacturer's recommendations and then applied on the inside surface of the pipe.

4. Mopping technique may be applied for coating the pipes.

5. The coated invert should extend the full length of the culvert for an arc of 90° or four inches beyond each side of the eroded surface, whichever is greater.

2. REHABILITATION TECHNIQUES

2.1 SLIP LINING

Application:

- Any type of culvert.

Definition:

Slip lining is the insertion of a prefabricated pipe inside the existing culvert. The lining may be metal, thermoset or thermoplastic, plastic, or concrete. If the pipe is rigid and is pushed into the existing culvert the process may be referred to as jacking.

Alternative materials:

Any conventional (or new) prefabricated culvert product may be used. Those most commonly used are corrugated metal pipe and plastic pipe. Polyethylene pipe may be preferable to PVC if the liner is exposed to sunlight which causes PVC to become brittle. Fiber glass pipe is not approved for culverts in California (Ref. 1).

Alternative methods:

- Pipe may be pushed and/or pulled into existing culvert.
- A guideway may be prepared, consisting of:
  - Pairs of wooden timbers
  - A concrete slab on centerline of the existing culvert
  - Pair of steel channels
  - Rail track and bogie vehicle (for large culverts)

- Pipe sections may be connected together:
  - Outside culvert (plastic and corrugated metal)
  - Inside culvert (plastic and concrete)
- Stabilization of the liner is achieved by grouting between the existing culvert and the liner. Liner must be blocked to avoid displacement or damage.
- The grout may be:
  - Portland cement based mortar
  - Controlled Low Strength and/or Low Density Material (CLSM)
  - Portland cement based mortar with foaming agent

Alternatives to slip lining:

Replacement; flexible tube lining; cement mortar lining; extensive patching; crack or joint repair; tunnel liner plates (for culvert diameters 48 inches or larger).

Advantages of slip lining:

- Provides a virtually new culvert comparable to replacement
- Medium cost compared to replacement
- Medium/high resource commitment compared to replacement

Disadvantages of slip lining:

- Reduces cross section area.
- May reduce hydraulic capacity.
- May increase velocity of flow.
- If liner is rigid pipe the existing structure alignment must be without elbows.
- In dry structures and with plastic liners there may be danger of fire.

Difficulties and precautions:

- Distortion of pipe may occur during insertion or grouting.
- Space is needed at ends of culvert for equipment.
- Heat from Portland cement grout can cause expansion of plastic pipes.
- Outside diameter of liner must have adequate clearance to pass deflected sections or poorly aligned joints of existing culvert.
- Hydraulic capacity and entrance and exit structures may be critical considerations.

Criteria for using slip lining:

- Extent of damage to culvert
- Needed future life of culvert
- Hydraulic adequacy of lined cross section
- Need to avoid disruption of traffic
- High embankment

Safety precautions:

Hydraulic jacking equipment presents hazardous working conditions and Cal-OSHA tunneling safety orders must be enforced.

Sources of information:

- Federal Highway Administration (Ref. 4)
- Indiana Department of Transportation (Ref. 10)
- California Department of Transportation (Refs. 2, 6, 7, 8, and 9)
- Hydro-Tech Inc. (Ref. 21)

Construction Methods

Site preparation:

1. Clean out pipe by flushing or by manual removal of debris.

2. Clean away loose material such as rust or spalls and remove protrusions.

3. Construct diversion dams and channels or pipes to control flow of water if necessary. The culvert does not need be totally dry but high flows will impede work.

4. Prepare work area large enough to contain the equipment, pipes, and a guideway for the lining pipe. (See pipe insertion.)

Pipe insertion:

1. The most common method is pushing pipes into culvert, but in some cases a pulling technique or combination of both may be used. Because of the large pressure load needed to push the last sections of pipe into place, pulling may be preferred to pushing if the culvert is large and long, and particularly if the new culvert pipe is reinforced concrete.

2. Equipment for pulling or pushing pipe into culverts normally consists of a winch and cable on a backhoe which is mounted on a tractor. The ease or difficulty of pipe insertion is a function of the roughness of the outside of the liner and protrusions on the inside of the culvert. Pushing a smooth plastic pipe into a small concrete pipe is easy, but lining a large corroded and distorted corrugated metal culvert is much more difficult. Similarly, pushing a ribbed pipe into a culvert is more difficult than pushing a smooth pipe,

especially if the existing culvert is corrugated metal with rivets.

3. For pulling a pipe into a culvert a strong back frame spanning one end of a single existing culvert is needed.

4. Some pushing jobs may require specialized equipment such as a jacking machine.

5. Pipe handling should be done carefully, keeping in mind that some types of pipe are very heavy, some need protection from impact loading (ex. precast concrete), and others are brittle in cold weather (ex. polyvinyl chloride).

6. Pipe lengths are typically 20 ft or 40 ft depending on the type of pipe; some types come in lengths of up to 80 ft.

7. For some types of pipe and/or pipe size sections must be joined before pushing into the culvert, for some types of large pipes sections can be joined after insertion.

Grouting of annular space:

1. Material should conform to the California Department of Transportation Standard Specifications.

2. Grouting of the annular space between the culvert and the lining should be done along the whole length of the culvert. See Figure 2.1.1. Grouting along the whole length provides additional strength if the liner alone does not have adequate strength.

3. Grouting: There are several different techniques for grouting the annular space between the culvert and the liner. In all these methods care must be taken to avoid

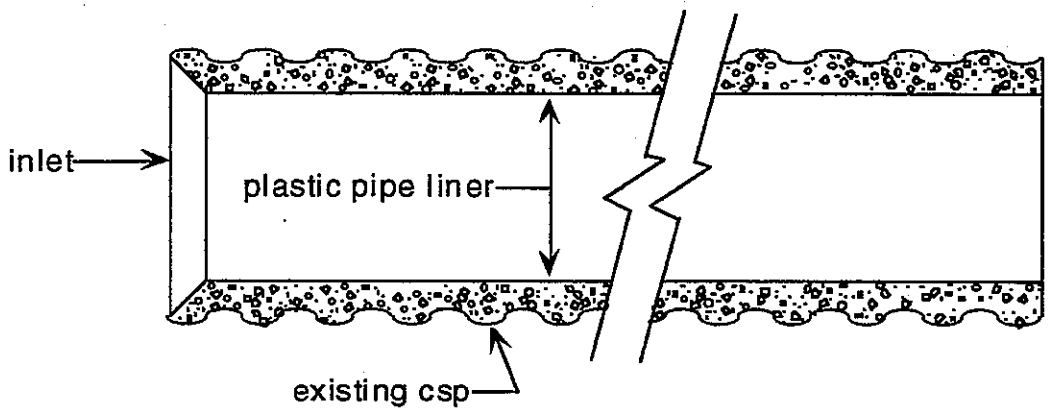


Figure 2.1.1. GROUTING OF ANNULAR SPACE BETWEEN INSERTED PIPE AND CULVERT

flotation of the liner. Some references call for blocking between liner and culvert. Low density grouts are also frequently used to avoid flotation of the liner. Another way to avoid flotation is application of the grout in two or three lifts. The techniques include the following: (a) Grout is applied through a standpipe at one end of the culvert until grout comes out at the bottom of the other end. The standpipe is installed through a hole in the existing culverts. The hole can be punctured through a concrete culvert, using a pointed steel rod. A cutting torch can be used to make the hole in a steel pipe. The standpipe should be grouted in place. (b) Grout is applied through grout ports in the liner at the top of the culvert until grout comes out at the bottom of the other end. (c) Grout is applied through a horizontal feeder pipe inserted into the bulkhead until grout comes out at the bottom of the other end. (d) Pressure grouting is applied through grout ports in the bottom of the liner pipe.

2.2 FLEXIBLE TUBE LINING

Application:

All types of culverts (size 6 inches to over 72 inches).

Definition:

Includes flexible pipes (tubes) inserted into culverts by inversion or by folding and subsequently expanding to full cross section. The techniques are proprietary methods to be undertaken by specialty contractors.

Alternative materials:

- Resin impregnated felt tube
- Polyurethane resin coating for interior surface of felt tube for smoothness
- PVC or polyethylene flexible pipes

Alternative methods:

- Inversion - (thermoset plastic) the tube is turned inside out during insertion
- Folded tube - the thermomechanically folded tube is reshaped after insertion

Alternatives to flexible tube lining:

- Slip lining
- Cement mortar lining
- Replacement (Jacking or micro-tunnelling)

Advantages of flexible tube lining:

- It bridges all joints and irregularities on the interior surface of the existing culvert.
- Because of its flexibility the liner conforms to barrels that are longitudinally curved or sections that are displaced with open joints between them.
- Depending on the thickness of liner and the type of the resin used, some structural strength may be provided to enhance the strength of the existing culvert.
- Flexible tubes easy to transport and handle.

Disadvantages of flexible tube lining:

- Specialized equipment and trained personnel needed.
- Stream flow carried by the culvert must be interrupted during installation and curing of the thermoset tube.

Difficulties and precautions:

Precautions must be exercised that the impregnated liner is kept cold until the culvert is properly prepared and the lining operation can proceed without stop.

Criteria for using felt tube lining:

- The presence of both exfiltration and infiltration of water through the walls and joints of the existing culvert.
- Existing culvert structurally sound.

Sources of information:

- Federal Highway Administration (Ref. 4)
- Indiana Department of Transportation (Ref. 10)

- Minnesota Department of Transportation (Ref. 11)
- Pennsylvania Department of Transportation (Ref. 28)
- GELCO (Ref. 19)

Construction Methods

2.2.1 Inversion method.

Inversion lining requires specialized equipment and is performed by specialty contractors.

Cleaning and inspection:

1. The water flow must be rerouted and the culvert should be cleared of all debris. The cleaning operation is often done by flushing with high-pressure water or water-jet. However, major amounts of debris may need to be removed with a dragline bucket.

2. Following cleaning, the culvert should be inspected to identify unanticipated problems that must be corrected prior to lining. A video film of the culvert may be made after it is cleaned.

Site preparation:

It may be necessary to do some repair or preparation work on the culvert prior to initiation of lining process, particularly to correct the following problems:

1. Loose plates of corrugated metal culverts may have to be secured.

2. Severely eroded or missing inverts with large voids in the soil may have to be filled with rock or concrete.

3. Culverts with a bituminous coating will have to be lined with a plastic tube barrier that will prevent chemical interactions with the liner resins. The culvert may be lined with a thin polyethylene preliner tube or coated with epoxy paint. When a plastic tube is used it is often inflated with a large capacity fan so that the liner can be inverted within it. For larger size culverts it may be more feasible to use an epoxy paint, provided that the culvert can be cleaned and dried before application of the paint.

Equipment setup:

1. Set up a vertical inversion standpipe tube, the boiler heat exchanger, and its suction and discharge lines.

2. The standpipe tube is needed to create the hydraulic head for water to turn the felt tube lining inside out and to completely fill the culvert. It is set up by attaching it to a construction scaffolding tower.

3. The tower height will vary with the diameter and depth of the culvert below grade, as well as thickness of the liner. The tower should be high enough to provide the required inversion head.

4. The inversion head may vary from a maximum of 38 feet for a 6 millimeter thick, 8 inch diameter liner, to as little as 12 feet on a 9 millimeter thick, 24 inch diameter liner.

5. Attach the upper end of the inversion tube to a metal rim provided on the scaffold, and attach the lower end to an elbow pipe section. Attach the liner to the other end of this elbow.

6. If there is a clearance problem, it may be necessary to eliminate the conventional inversion tube and instead attach the inversion liner directly to the ring on the scaffold platform. This is more costly because of the additional liner material needed.

Inversion process:

1. Insert the flexible tube lining into the inversion standpipe and cuff it around the outlet at the bottom of the inversion tube. This places the resin side of the lining against the inside of the culvert.

2. Position the bottom of the inversion tube in the damaged culvert.

3. Cold water is pumped into the top of the inversion tube.

4. As water is added the static pressure created by the tall inversion tube causes the liner to turn inside out and move through the culvert, conforming to the shape of the culvert.

5. The rate at which the liner moves through the culvert is controlled by the static pressure head and by a rope that is attached to the pre-measured liner. A perforated hot water tube is also attached to the trailing end of the liner.

Curing:

1. Once the liner has been fully extended through the culvert, the cold water inside the liner is skimmed off at the top of the standpipe, recirculated through a truck mounted boiler-heat exchanger, heated and pumped deep into the culvert through the perforated hot water tube.

2. The 150° to 200°F water causes the thermo-setting polyester and polyurethane resins to cure, harden and become permanently set against the inside of the culvert within a few hours. The curing time is dependent upon the length and thickness of the liner.

3. The water temperature is monitored throughout the curing process by wire thermocouples that are inserted in the ends of the culvert. It should be noted that the heat-sink characteristics of the culvert and the ground can vary greatly and cause differences between the temperatures of the circulating water and the liner bag outer surface. Thus the temperature of the circulating water should not be used as the only criteria for determining the extent to which curing process has proceeded.

4. After the resin has cooled, the hot water is slowly drained through a small hole that is cut at the outlet end of the liner. As a safety measure personnel should not be allowed downstream of the culvert during curing period.

5. After the curing water is drained, the protruding stiffened ends of the liner are cut off with a carbide-tipped rotary saw and work on the ends of the culvert is completed.

Inspection:

1. The final step in the process is to inspect the culvert to ensure that the liner has been properly installed. Problems that are detected should be corrected at that time.

2. A videofilm of the installation process should be made.

3. Special specimens may be prepared or samples of the completed work may be taken for subsequent testing and

acceptance of the work. This may include lining of additional short length of culvert with the material which is then removed so that measurements can be taken and testing can be done.

4. Core samples may be taken from the barrel of the culvert for measurement of the lining thickness.

2.2.2 Folded tube method.

Folded tube lining requires specialized equipment and is performed by licensed contractors.

Site preparation:

1. Re-route the water flow and clean away all dirt, scale, loose materials and all other foreign materials. This may be done by flushing with high-pressure water or water-jet. Any standing water should be expelled out of the pipe.

2. Prepare working space large enough for staging and equipment setup at both ends of the culvert.

Installation procedure:

1. After cleaning operation the heat-containment tube is pulled through the culvert and inflated.

2. The folded tube lining is heated until it becomes flexible enough to be pulled through the host pipe and heat containment tube. The liner is then ready to be rounded.

3. A rounding device is inserted into the upstream end of the flexible tube lining. The device is propelled by steam pressure to the downstream termination point. As the

rounding device progresses, it expands the lining tight against the walls, molding it to the shape of the host pipe.

4. Pressure is maintained in the rounded lining until it cools to a rigid state.

5. Finally, the ends of the lining are cut off to the exact length of the host pipe.

2.3 CEMENT MORTAR LINING

Application:

Cast-iron, steel, concrete, brick, and smooth and corrugated steel and pipelines or pipe culverts ranging from 4 inches to 20 feet in diameter.

Definition:

Cement mortar lining is the application of a layer of cement mortar on the inside of the culvert.

Alternative materials:

- Cement/sand mortar
- Cement/sand mortar containing special admixtures to facilitate placement, minimize drying and shrinkage cracks, and improve durability, including the use of air entrainment for freeze-thaw resistance.

Alternative methods:

- With mechanized equipment (centrifugal process)
- Pneumatically by the shotcrete method (gunite method). Steel mesh or reinforcing bars may be used as an option (diameters less than five feet).

Alternatives to cement mortar lining:

Slip lining; felt tube lining, replacement.

Advantages of cement mortar lining:

- Eliminates leakage
- Reduces surface roughness and improves flow capacity, especially for corrugated structures
- Improves corrosion resistance
- It will not significantly reduce the hydraulic capacity of the culvert

Disadvantages of cement mortar lining:

- The liner may not bond with the existing culvert
- The liner may crack and separate from the existing culvert
- Corrosion of metal culvert surface may occur causing separation of lining

Difficulties and precautions:

- The existing culvert must be completely cleaned and flow must be diverted before lining.
- Spot patching or repairs may be needed to fill large voids under deteriorated inverts.
- There must be sufficient space on or adjacent to the roadway above the culvert for setting up the mortar mixing equipment.

Criteria for using cement mortar lining:

- Culvert is structurally sound
- Surface roughness causes inadequate hydraulic capacity

Safety precautions:

The potential of problems and injury during construction with gunite should be recognized and avoided. The materials are

transported by high pressure air through hoses which are difficult to control and which could break. The process is noisy which can cause ear damage. The cement dust in the air can cause eye damage.

Sources of information:

- Indiana Department of Transportation (Ref. 10)
- California Department of Transportation, Districts 1 and 5 (Refs. 7 and 9)
- Federal Highway Administration (Ref. 4)

Construction Methods

Cement mortar can be applied either by manual process or by using a centrifugal process. The most common method is centrifugal. Materials should conform to the California Department of Transportation Standard Specifications.

Site preparation:

1. Clean away all dirt, scale, loose or deteriorated remnants of old lining materials and all other foreign materials. This may be done by flushing with high pressure water or waterjet. Large diameter culverts may be cleaned by working with hand tools. The cleaning may also be done by specially developed mechanized equipment developed specially for this lining process.

2. The culvert does not need to be completely dry but the flow should be rerouted during the application of cement lining material.

3. If needed spot patching or repairs may be done to maintain structural integrity and to fill large voids beneath the

deteriorated inverts with cement mortar.

4. Prepare working space large enough for staging and equipment setup at one or both ends of the culvert.

Equipment:

The centrifugal process uses a lining machine which dispenses and trowels mortar on the interior surface of the pipe through an application head.

Other equipment includes a machine for mixing the mortar and a method of transporting the mortar to the culvert.

It should be noted that these types of equipment are large and a certain amount of space is required for staging and equipment setup on one or both ends of the culvert.

Lining operation:

1. Mortar should conform to California Department of Transportation Standard Specifications. Thickness of the lining will vary with pipe size and cause of deterioration.

2. The mortar lining method used for culverts should be a continuous process which is not stopped until the entire culvert has been lined.

3. For lining culverts up to 36 inches in diameter the mortar is applied by a spinning spray-type head which centrifugally projects the mortar against the pipe surface without rebound, but with sufficient velocity to cause the mortar to be densely packed in place. The distribution head is pulled through the pipe by a cable and a winch system. After it is applied, the mortar is compacted and its surface is smoothed

by a flexible conical-shaped trowel that is pulled through the line with the mortar placement machine. Excess materials, spatter, and other undesirable substance accumulating along the pipe invert should be removed ahead of the trowels.

4. Culverts larger than 36 inches in diameter are lined with a larger machine which places, compacts, and smoothes the mortar with two or more rotating trowels or which places the concrete by the gunite method. The machine is usually controlled by an operator riding on the machine.

2.4 JACKING

Application:

Replacing existing structure to increase capacity, improve alignment, etc.

Definition:

This is the process of pushing a conduit through an embankment. Embankment material would be removed through the conduit being jacked by a fleet of augers or other suitable excavation methods.

Alternative materials:

Reinforced concrete pipe, steel pipe.

Alternative methods:

Diameters 48 inches or larger, steel tunnel liner plates.

Alternatives to replacement by jacking:

Open cut through embankment or tunneling.

Advantages of replacement by jacking:

- Provides a new culvert
- Allows using larger pipe to increase capacity
- Economical where access is available at the site and embankment can be cut by augers

Disadvantages of replacement by jacking:

- Unsuitable embankment - large rocks, etc.
- Alignment must be straight
- Soil friction on the structure may limit length where jacking pressure would exceed the longitudinal strength of the conduit

Difficulties and precautions:

- Intermediate jacking stations are required at either vertical or horizontal alignment changes and may be required for long structures.
- Pipe ends must be well fitted and aligned to distribute the jacking pressure to each section.
- If sand pockets are encountered voids may develop around the pipe. These voids should be filled by grouting or other means.

Criteria for using replacement by jacking:

- Need for more hydraulic capacity
- Improvement of existing structure location
- Existing structure's alignment or shape will not permit relining

Safety precautions:

Hydraulic jacking presents hazardous working conditions and Cal-OSHA tunneling safety orders must be enforced.

Sources of information:

- Federal Highway Administration (Ref. 4)
- Indiana Department of Transportation (Ref. 10)

Construction Methods

Jacking shall be performed in accordance with California Department of Transportation Standard Specifications (Section 65-1.05).

The usual construction sequence for tunneling and jacking is:

1. Excavate jacking pits or shafts, construct jacking abutments or thrust blocks, and install jacks, jacking frame, and guide rails. See Figure 2.4.1.

2. Begin tunnel excavation by machine or hand, depending upon the conditions.

3. Lower first section of pipe, position jacks and jacking frame, and jack pipe forward.

4. Continue excavation by any suitable method, removing soil through pipe. Insert succeeding sections of pipe between lead pipe and jacks, and jack forward. It is essential that the pipe ends are parallel so that there will be a relatively uniform distribution of forces around the periphery of the pipe. The alignment and grade should be monitored and adjusted as jacking proceeds.

5. The jacking operation should be done in a continuous operation because, if forward movement is stopped, the pipe tends to set or freeze, which then creates considerable resistance to subsequent jacking forces.

6. Repeat sequence, excavation, soil removal, pipe insertion and jacking, until the operation is complete. For long culverts it may be necessary to establish intermediate jacking stations so that predetermined jacking forces will not be exceeded.

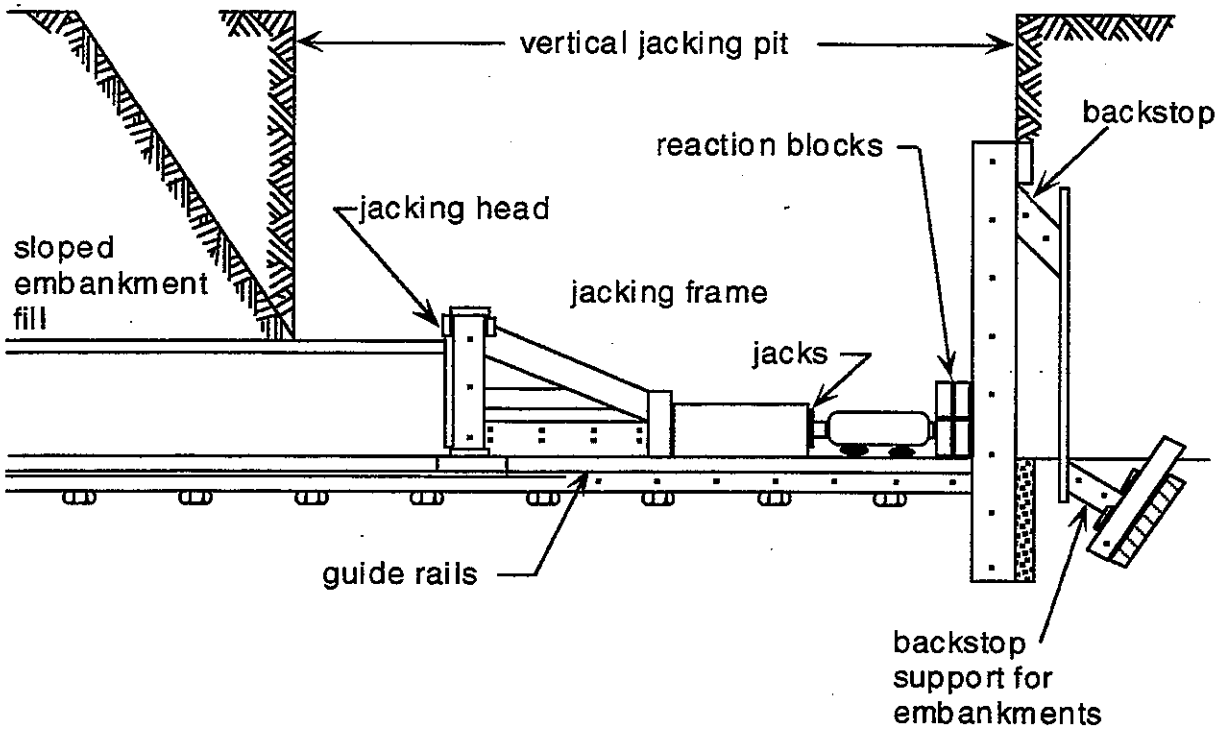


Figure 2.4.1 TYPICAL EQUIPMENT SETUP
FOR PIPE JACKING

2.5 MICRO-TUNNELING

Application:

Any type of culvert (diameters less than three feet).

Definition:

This is the process of tunneling and pushing a pipe through the tunnel as work proceeds.

Alternative materials:

- Reinforced concrete
- Poly-vinyl chloride

Alternative methods:

- Micro-tunneling machine with cutting head
- Slurry pumping system

Alternatives to micro-tunneling:

- Slip lining
- Felt tube lining
- Cement mortar lining

Advantages of micro-tunneling:

- Larger pipe can be used to increase hydraulic capacity
- Can be used to replace small diameter culverts in soft, unstable, water bearing soils

- May use laser guided and remotely controlled equipment which can be monitored and accurately adjusted for alignment

Disadvantages of micro-tunneling:

- Cannot be used for culverts over 36 inches in diameter.

Criteria for using micro-tunneling:

- Existing culvert not structurally sound
- Existing culvert too small for workers to enter

Sources of information:

- Federal Highway Administration (Ref. 4)
- Indiana Department of Transportation (Ref. 10)
- Miller Pipeline Corporation (Ref. 23)

Construction Methods

Micro-tunneling may be used for culvert sizes up to 36 inches. The micro-tunneling machine uses a rotary cutting head to grind the old pipe and cut into the surrounding soil. Micro-tunneling is generally performed by specialized contractors sometimes using proprietary equipment and pipe.

Site preparation:

1. Prepare sufficient space at one of the ends of the culvert to set up the micro-tunneling machine and the push pit for the jacks.

2. Space for the slurry pumping machine can be prepared on or adjacent to the roadway above the culvert if space is not

available at the end.

Procedure:

1. Set up the micro-tunneling machine, the jack, and the slurry pumping machine.

2. During the cutting process a constant pressure should be maintained at the cutting head to prevent collapse. This can be done by utilizing slurry under pressure or by using an expanding cutting head. The broken up old pipe and any surrounding soil may be mixed into the slurry which is pumped to the surface where it is settled out in tanks. The slurry is then recirculated to the cutting head in the process. Alternatively the broken pipe may be forced outward into the surrounding soil.

3. The machine is moved ahead by pushing in new pipe behind it using powerful hydraulic jacks in the push pit.

4. The alignment and grade should be monitored and accurately adjusted as the micro-tunneling proceeds.

REFERENCES

1. Coates, Dean; California Department of Transportation. (Verbal and written communication, 1993)

2. DeVito, Joe; District 4; California Department of Transportation. (Verbal and written communication, 1991)

3. Federal Highway Administration; Culvert Inspection Manual; FHWA-IP-86-2; US Department of Transportation; July 1986

4. Federal Highway Administration; Culvert Repair Practices Manual (Draft Final Report); US Department of Transportation; April 1992

5. Federal Highway Administration; Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges; FHWA-ED-89-044; US Department of Transportation; December 1988

6. Gaunt, Chuck; District 11; California Department of Transportation (verbal and written communication).

7. Hendrikson, Steve; District 5; California Department of Transportation (verbal and written communication).

8. Kraetsch, Robert; District 10; California Department of Transportation (verbal and written communication).

9. McBride, Dennis; District 1; California Department of Transportation (verbal and written communication, 1991)

10. McCulloch, Bob; Repair and Rehabilitation of Deteriorated Drainage Pipe; Indiana Department of Transportation and Federal Highway Administration; FHWA/IN/JHRP 91/14; Oct. 1991

11. Minnesota Department of Transportation; Culvert Renewal; Minnesota Department of Transportation MN/RD-92-02; April 1992

12. Wilson-Broades, Susan; District 2; California Department of Transportation (verbal and written communication, 1991)

Additional Sources of Information

13. Alabama Highway Department, 1952
(for armoring corrugated metal pipe inverts with steel plates)

14. Alberta Transportation and Utilities
(for repair of joints with a shotcrete beam)
Regional Transportation
South Central Region
P. O. Box 3550
925 Irricana Road
Airdrie, Alberta, Canada T4B 2B7
Phone (403) 948-8420

15. Asphalt Institute
1832 Tribute Road
No. 214-216
Sacramento, CA 95815
Phone (916) 922-6507

16. American Concrete Institute
Box 19150 Redford Station
Detroit, Michigan 48219
Phone: (313) 532-2600
FAX: (313) 538-0685

(ACI Manual of Concrete Practice; ACI 224.1 R-84
ACI Guide to Shotcrete; ACI 506R-90)

17. California Department of Transportation
Standard Specifications

18. Colorado Highway Department
(for armoring concrete box culverts with steel plates)
(for paving with high strength concrete)

19. GELCO
(Insituform and Nupipe)
8565 Elder Creek Road
Sacramento, CA 95828
Phone: (916) 383-4466
FAX: (916) 383-0480

20. GKN Hayward Baker
(for grouting)
P. O. Box 7690
Ventura, CA 93006
Phone: (805) 933-1311

21. Hydro-Tech Inc.
155 Lyon Drive
Fernley, Nevada 89408
Phone: (702) 575-4100 Nevada
FAX: (801) 269-9009 Utah

22. Indiana Department of Transportation
(for crack repair by chemical grout)

23. Miller Pipeline Corporation
<u>XPANDIT Trenchless Pipe Replacement</u>
P. O. Box 34141
Indianapolis, Indiana 46234
Phone: (317) 293-0278

24. National Corrugated Steel Pipe Association
Rehabilitation of Corrugated Steel Pipe and Pipe Lines of Other Materials, Drainage Technology Bulletin, Sept. 1988

25. Ohio Department of Transportation
(for paving with wire mesh reinforced concrete)

26. Oregon Highway Department
(for armoring concrete box culverts with steel grid bridge decking and old railroad rails)

27. Pacific Corrugated Pipe Co.
P. O. Box 2450
Newport Beach, CA 92658
Phone: (714) 630-4555

28. Pennsylvania Department of Transportation
(for repair of cracks by injection of epoxy adhesive)

29. Pressure Grout Company
1975 National Avenue
Hayward, CA 94545-1709
Phone: (510) 887-2244
FAX: (510) 887-8342

30. U. S. Army Corps of Engineers
(for paving with fibrous concrete)

APPENDIX A

SAMPLE CULVERT CONDITION REPORT FORM

COUNTY_____ROUTE_____PM_____DATE_____INSPECTOR_____

1. SITE INFORMATION:

Is inlet and outlet readily accessible (Y/N)?_____
If no for either, describe existing conditions.
_____
_____

2. STREAM FLOW CONDITION:

[] intermittent - during storms only
[] continuous - winter and spring [] continuous - full year
Headwater (above invert). Estimate max elev_____ft.
Tailwater (above invert). Estimate max elev_____ft.
Fish barrier at either inlet or outlet (Y/N)? _____
If yes, describe_____
_____
Debris in culvert? [none(N), light(L), moderate(M), severe(S)]_____. Describe debris_____
_____
pH of water?_____

3. INLET AND OUTLET STRUCTURES:

Type: [] square end projecting [] cut to match fill slope
[] prefabricated end sections [] concrete (cast in place)
[] other: describe_____

4. GENERAL CULVERT INFORMATION:

Culvert requires cleaning to inspect (Y/N)?_____
Roadbed above structure shows distress (Y/N)?_____
If yes, describe_____

_____

SHAPE: [] round, [] arch, [] pipe arch, [] box, [] oval,
[] long span, [] other (describe)_____
SIZE: clear height_____in., clear span_____in.
Is culvert size and alignment adequate for inspection team to pass through (Y/N)?_____
MATERIAL: [] cast in place concrete, [] concrete (precast),
[] asbestos cement, [] steel, [] aluminum
Existing coating, paving or lining (Y/N)?_____
If yes, comment on type, material, and condition_____

_____

_____

Date of installation (if known)_____

5. CONTINUE ON THE ATTACHED FORM (A THROUGH D) FOR THE APPROPRIATE CULVERT TYPE

A. UNREINFORCED CONCRETE

1. EROSION/CORROSION:

Does the culvert show invert wear (Y/N)?_____
If yes, measure invert loss @ 12" intervals and draw profile along invert.
Is maximum invert loss > 25% (Y/N)?_____
If yes, draw cross section profile at maximum wear.
Size of maximum bedload aggregate:
[] size<1", [] 1"<size<4", [] size>4"

2. STRUCTURAL EVALUATION:

Are cracks or spalls visible (Y/N)?_____
If yes for cracks, they are [] circumferential,
[] longitudinal,
[] diagonal.

Note any shape change in the vicinity of the crack, including offset of pipe wall. Locate (from inlet) each crack on a sketch with crack thickness noted.

If yes for spalls, locate (from inlet) each and describe on sketch with measure of material loss.

Based on Report Number F.H.W.A.-ED-89-044 pp. 39-40, what rating code is appropriate for the overall structural condition of the culvert?_____

B. REINFORCED CONCRETE

1. EROSION/CORROSION:

Does the culvert show invert wear (Y/N)?_____
If yes, are reinforcing bars exposed (Y/N)?_____
Are rust stains noted from unexposed bars (Y/N)?_____
Locate (from inlet) worn invert sections and estimate loss of wall thickness for each section.

Size of maximum bedload aggregate:
[] size<1", [] 1"<size<4", [] size>4"

2. STRUCTURAL EVALUATION:

Are cracks or spalls visible (Y/N)?_____
If yes for cracks, they are [] circumferential,
[] longitudinal,
[] diagonal.
Note any shape change in the vicinity of the crack, including offset of pipe wall. Locate (from inlet) each crack on a sketch with crack thickness noted.

If yes for spalls, locate (from inlet) each and describe on sketch with measure of material loss.

Based on Report Number F.H.W.A.-ED-89-044 pp. 39-40, what rating code is appropriate for the overall structural condition of the culvert?_____

C. CORRUGATED ALUMINUM AND STEEL

1. EROSION/CORROSION:

Does the culvert show invert wear (Y/N)?_____

If yes, rate the condition of the invert:

[] superficial corrosion and no pitting

[] significant corrosion and/or moderate pitting

[] significant corrosion and/or deep pitting

[] extensive corrosion and/or deep pitting

[] extensive corrosion, deep pitting, perforation.

For last three conditions, locate by angles from invert, the furthest extent of the corroded area; obtain soil resistivity.

Size of maximum bedload aggregate:

[] size<1", [] 1"<size<4", [] size>4"

2. STRUCTURAL EVALUATION:

Is the shape of the cross section uniform throughout its entire length (Y/N)?_____

If no, locate (from invert) the distorted sections; measure and sketch the modified shapes.

Is there a loss of backfill (Y/N)?_____

If yes, locate (from invert) and describe loss on a sketch.

Is there evidence of piping (Y/N)?_____

If yes, locate (from invert) and describe.

Based on Report Number F.H.W.A.-ED-89-044 pp. 39-40, what rating code is appropriate for the overall structural condition of the culvert?_____

D. PLASTIC

1. EROSION/CORROSION:

Does the culvert show invert wear (Y/N)?_____

If yes, rate the condition of the invert:

[] superficial

[] significant

[] extensive, no perforation

[] extensive, perforation.

For last three conditions, locate by angles from invert, the furthest extent of the worn area.

Size of maximum bedload aggregate:

[] size<1", [] 1"<size<4", [] size>4"

2. STRUCTURAL EVALUATION:

Is the shape of the cross section uniform throughout its entire length (Y/N)?_____

If no, locate (from invert) the distorted sections; measure and sketch the modified shapes.

Is there a loss of backfill (Y/N)?_____

If yes, locate (from invert) and describe loss on a sketch.

Is there evidence of piping (Y/N)?_____

If yes, locate (from invert) and describe.

Based on Report Number F.H.W.A.-ED-89-044 pp. 39-40, what rating code is appropriate for the overall structural condition of the culvert?_____

APPENDIX B

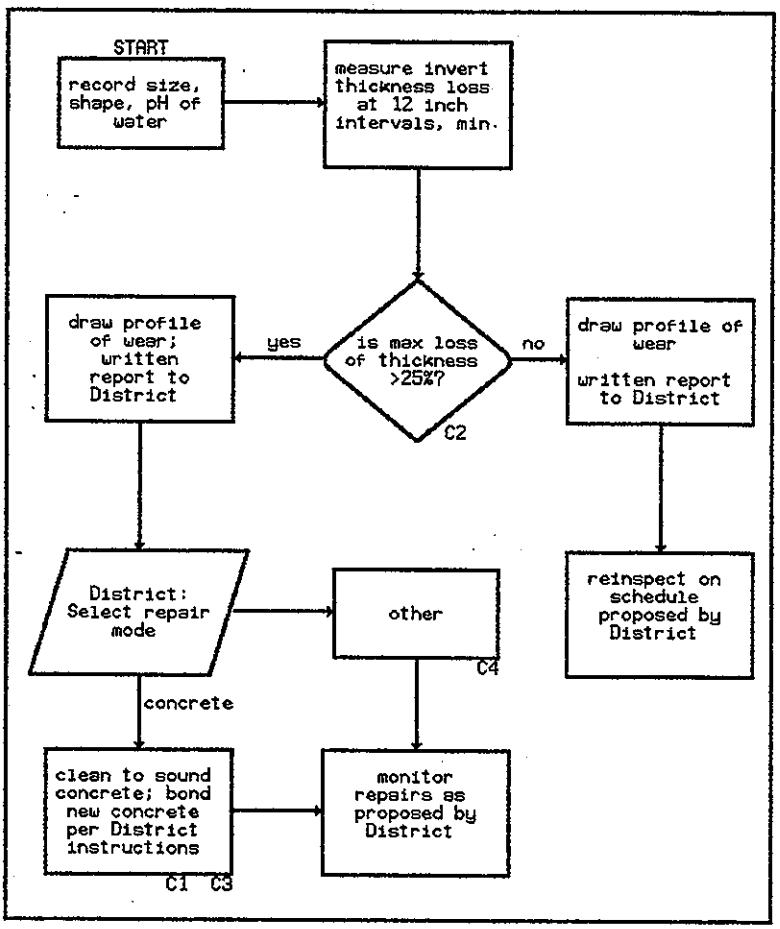
PROCESS FLOW CHARTS

TABLE OF CONTENTS

		Page
1.	Unreinforced Concrete: Invert Wear.	B-2
2.	Reinforced Concrete: Invert Wear; Bars Not Exposed	B-3
3.	Reinforced Concrete: Invert Wear; Bars Exposed. . .	B-4
4.	Steel: Erosion/Corrosion.	B-5
5.	Aluminum: Erosion/Corrosion	B-6
6.	Plastic: Erosion/Corrosion	B-7
7.	Unreinforced Concrete: Cracks and Spalls	B-8
8.	Reinforced Concrete: Cracks and Spalls.	B-9
9.	Precast Concrete: Joint Separation.	B-10
10.	Metal or Plastic: Structural Problems	B-11

UNREINFORCED CONCRETE:

INVERT WEAR



GENERAL NOTES:

All concrete culverts will show some noticeable wear after a period of service. The beginning of rutting of the invert should trigger interest in reporting wear. Once rutting has begun, wear should be expected to proceed at an accelerated rate.

COMMENTS:

C1. Diversion of stream may require passage of fish.

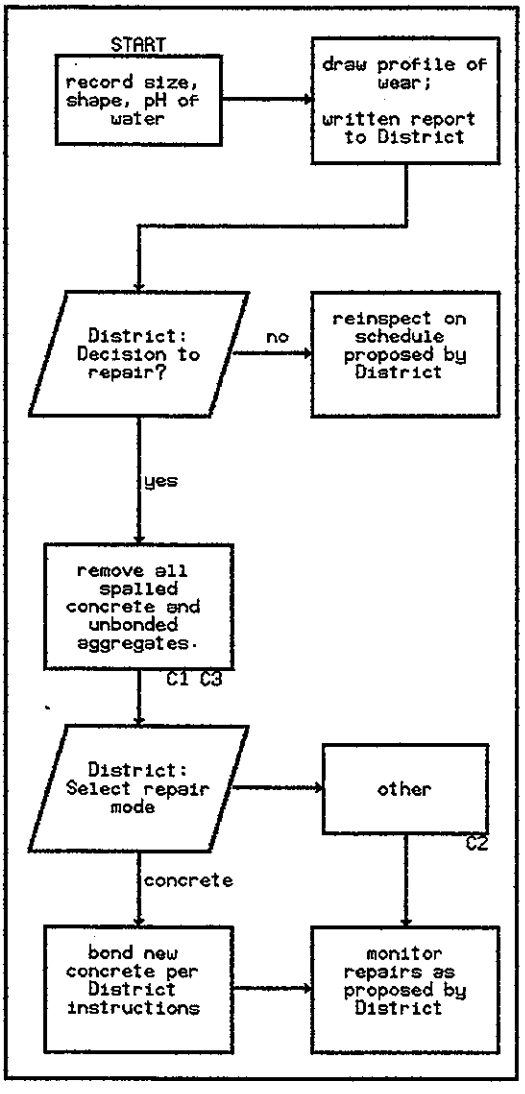
C2. The % loss of thickness should be calculated using the nominal thickness as a basis. Check with District as to the appropriateness of the criterion of a 25% loss of thickness.

C3. The new concrete will bond to the old concrete only if the old concrete is free of all dust, grease and/or grime. See Part II;1;1.7.3 for additional details.

C4. Alternatives include linings, pavings and platings. See Part II;1;1.7-10.

REINFORCED CONCRETE:

INVERT WEAR; BARS NOT EXPOSED



GENERAL NOTES:

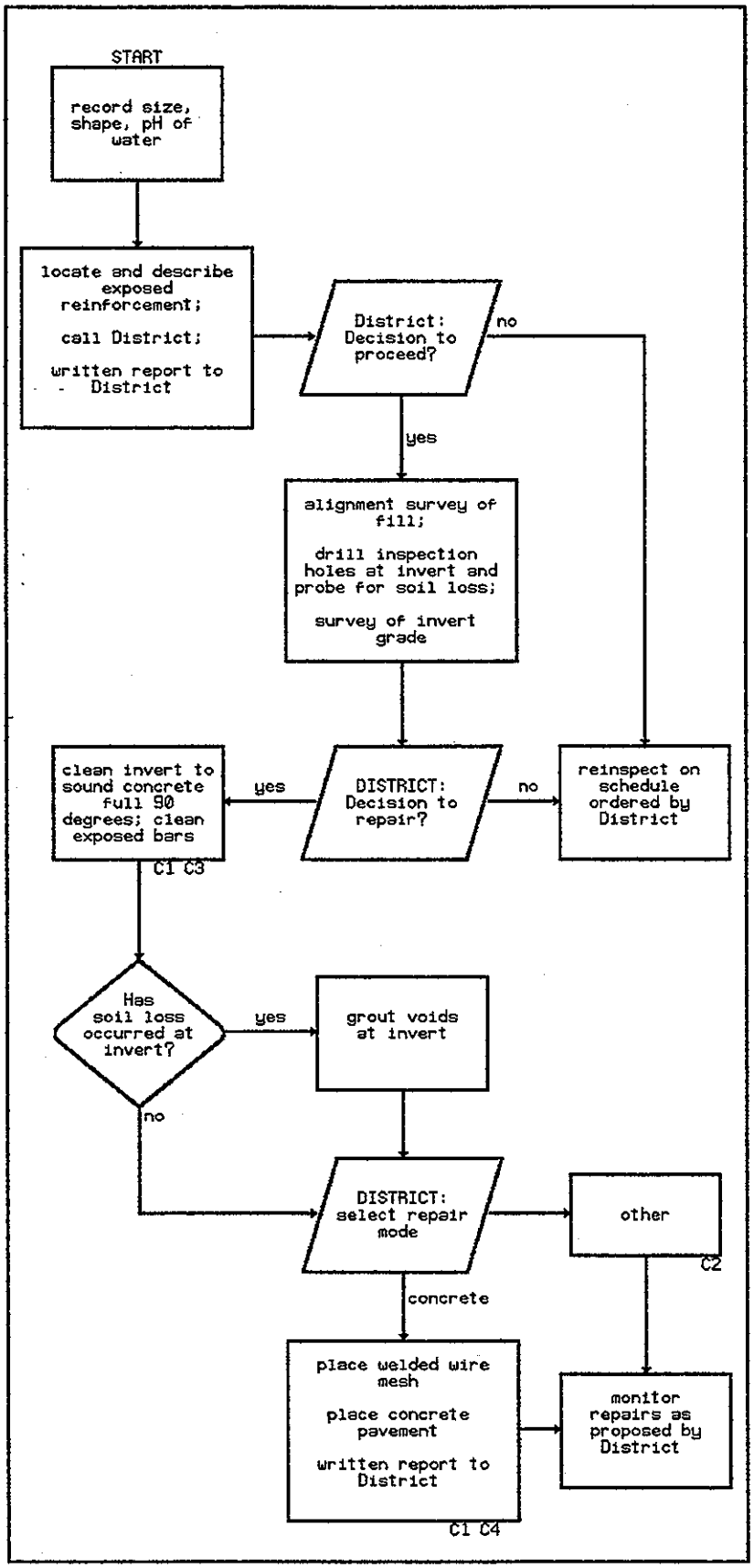
All concrete culverts will show some noticeable wear after a period of service. The beginning of rutting, or the onset of rust stains, at the invert should trigger interest in reporting wear. Once rutting, or corrosion of the steel reinforcement has begun, degradation of the invert should be expected to proceed at an accelerated rate.

COMMENTS:

C1. Diversion of stream may require passage of fish.

C2. Alternatives include linings, platings and pavings. See Part II;1;1.7-10.

C3. The final surface is to be free of all dust, grease and/or grime to assure adequate bonding of new paving to old. See Part II;1;1.7.3 for additional details.



REINFORCED CONCRETE:

INVERT WEAR, BARS EXPOSED

GENERAL NOTES:

All concrete culverts will show some noticeable wear after a period of service. The beginning of rutting, or the onset of rust stains, at the invert should trigger interest in the reporting of wear. Once rutting or corrosion of steel reinforcement has begun, degradation of the invert should be expected to proceed at an accelerated rate.

Although the bond between the reinforcement and the concrete may be broken before the bars are exposed by continued wear, there is no question that bond is absent when bars are exposed. This has very serious structural implications in that such steel that was designed to carry internal forces resisting earth and live loads is no longer functioning as intended. The concrete alone should never be assumed to be capable of carrying the noted loads.

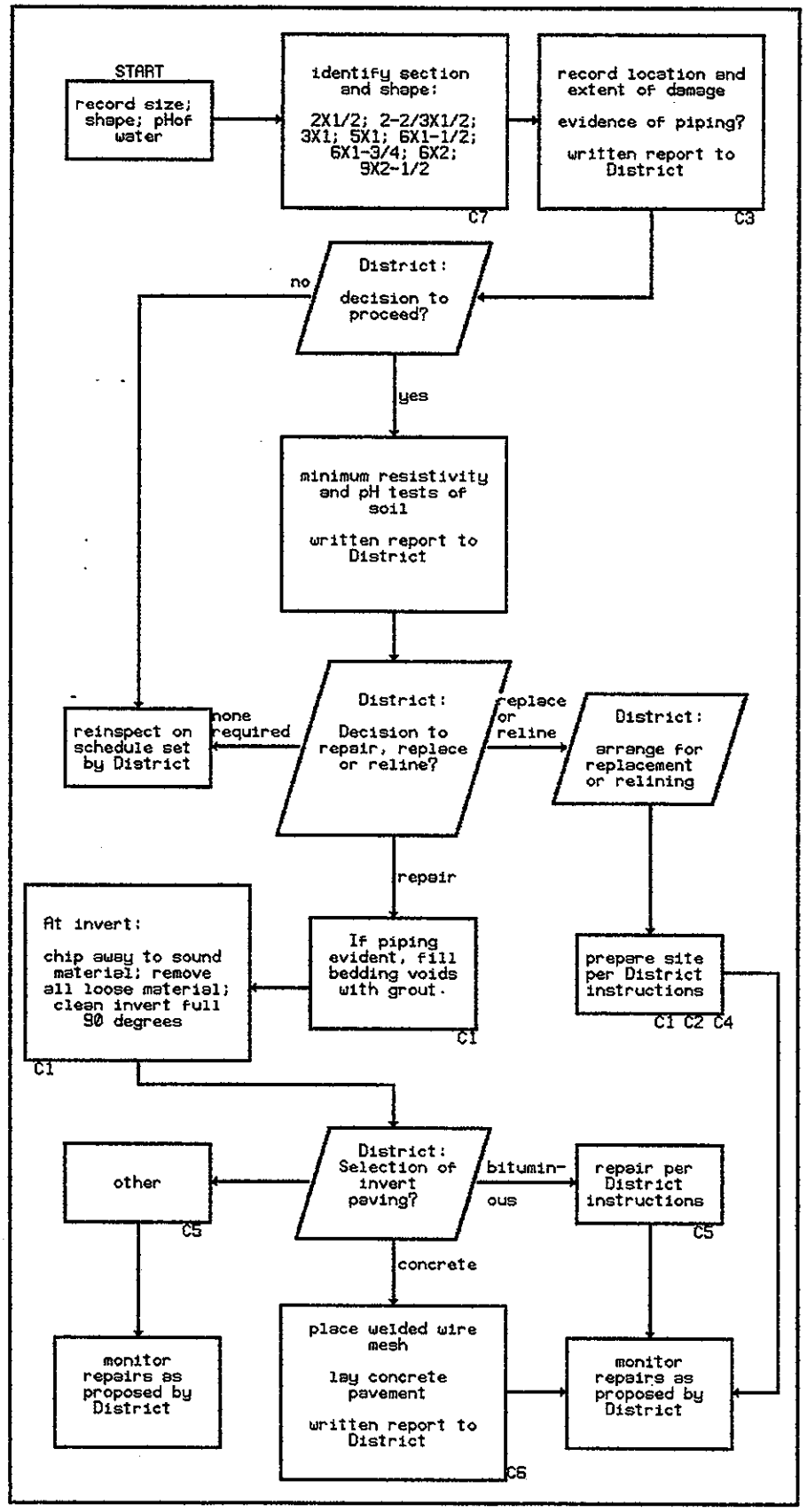
COMMENTS:

C1. Diversion of stream may require passage of fish.

C2. Alternatives include linings, pavings and platings. See Part II;1;1.7-10.

C3. The final concrete and steel surfaces are to be free of all dust grease and/or grime; the steel is to be free of all corrosion products. See Part II;1;1.7.3 for additional details.

C4. For details see Part II;1;1.7.2.



STEEL:

EROSION/ CORROSION

GENERAL NOTES:

Once the galvanized outer layer of the corrugated steel has been penetrated by the abrasive actions of the bed load of gravels transported through the culvert, the unprotected steel may be expected to rapidly deteriorate. It may then be desirable to increase the frequency of inspections.

COMMENTS:

C1. Diversion of stream may require passage of fish.

C2. May require redesign of channel for fish migration.

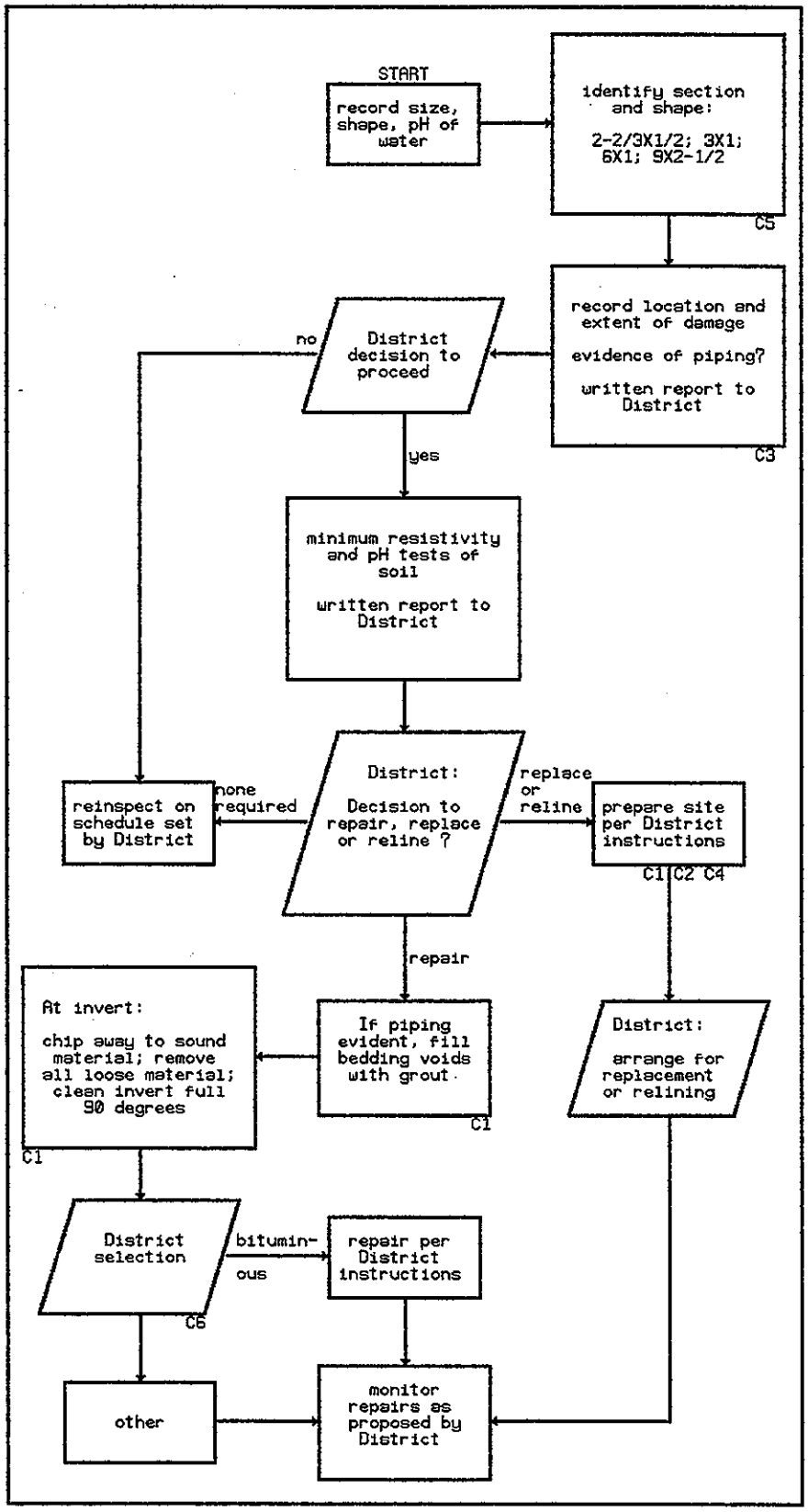
C3. Piping may result in serious structural failure and/or embankment instability.

C4. Should an outside sliplining contractor be engaged, it is important to receive the contractor's instructions for site requirements, including required working space.

C5. Bituminous, resin and other linings, platings and coatings have to satisfy fire, safety, and environmental standards and/or requirements. See Part II;1;1.7-10 for alternatives.

C6. For details see Part II;1;1.7.2.

C7. The sections noted are standard sections that are currently in production or have been in production in the past. The listing provided may be incomplete.



ALUMINUM:

EROSION/ CORROSION

GENERAL NOTES:

When aluminum and Portland cement are in contact, corrosion may result. It is therefore important to obtain the advice of the District before putting these two materials in contact. For instance, a Portland cement concrete grout may be permitted, whereas a Portland cement slurry grout may be prohibited.

COMMENTS:

C1. Diversion of stream may require passage of fish.

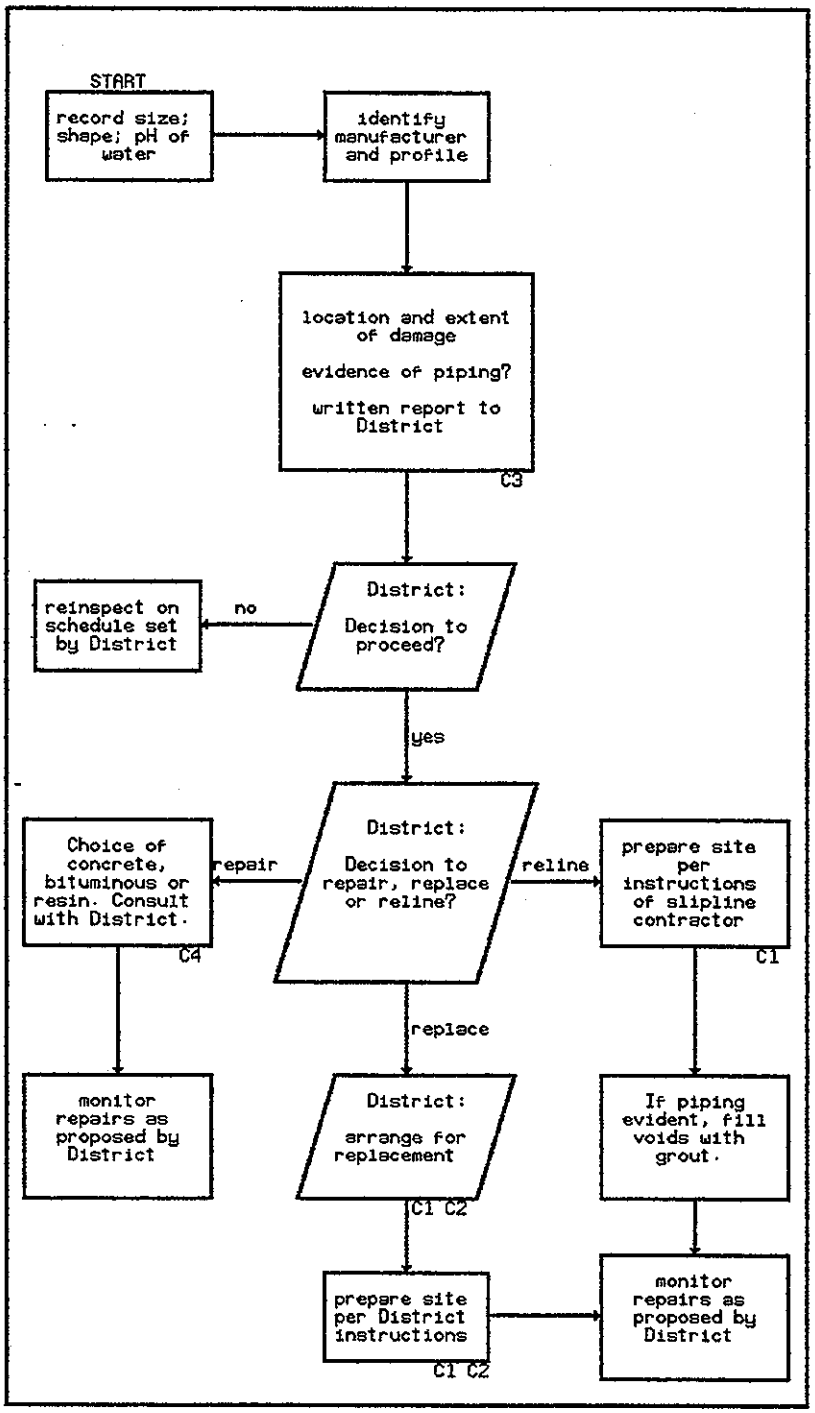
C2. May require redesign of channel for fish migration.

C3. Piping may result in serious structural failure and/or embankment instability.

C4. Should an outside sliplining contractor be engaged, it is important to receive the contractor's instructions for site requirements, including required working space.

C5. The sections noted are standard sections that are currently in production or have been in production in the past. The listing provided may be incomplete.

C6. Bituminous, resin and other coatings have to satisfy fire, safety, and environmental standards and/or requirements. See Part II;1;1.7-10 for alternatives.



PLASTIC:

EROSION/
CORROSION

GENERAL NOTES:

Unlike the case with corrugated metal culverts, the wall profiles of plastic culvert pipes are not made to any industry standard. Therefore, experience with one plastic culvert is not necessarily transferable to other plastic culverts.

Recognizing invert wear in plastic culverts may be more difficult than in concrete or metal culverts. The pattern of wear is likely to be without rutting or visual evidence of corrosion. The worn invert will appear smooth and somewhat polished. The absence of circular or spiral patterns (a result of the manufacturing process) in the vicinity of the invert may be the only visual evidence from which invert wear may be deduced.

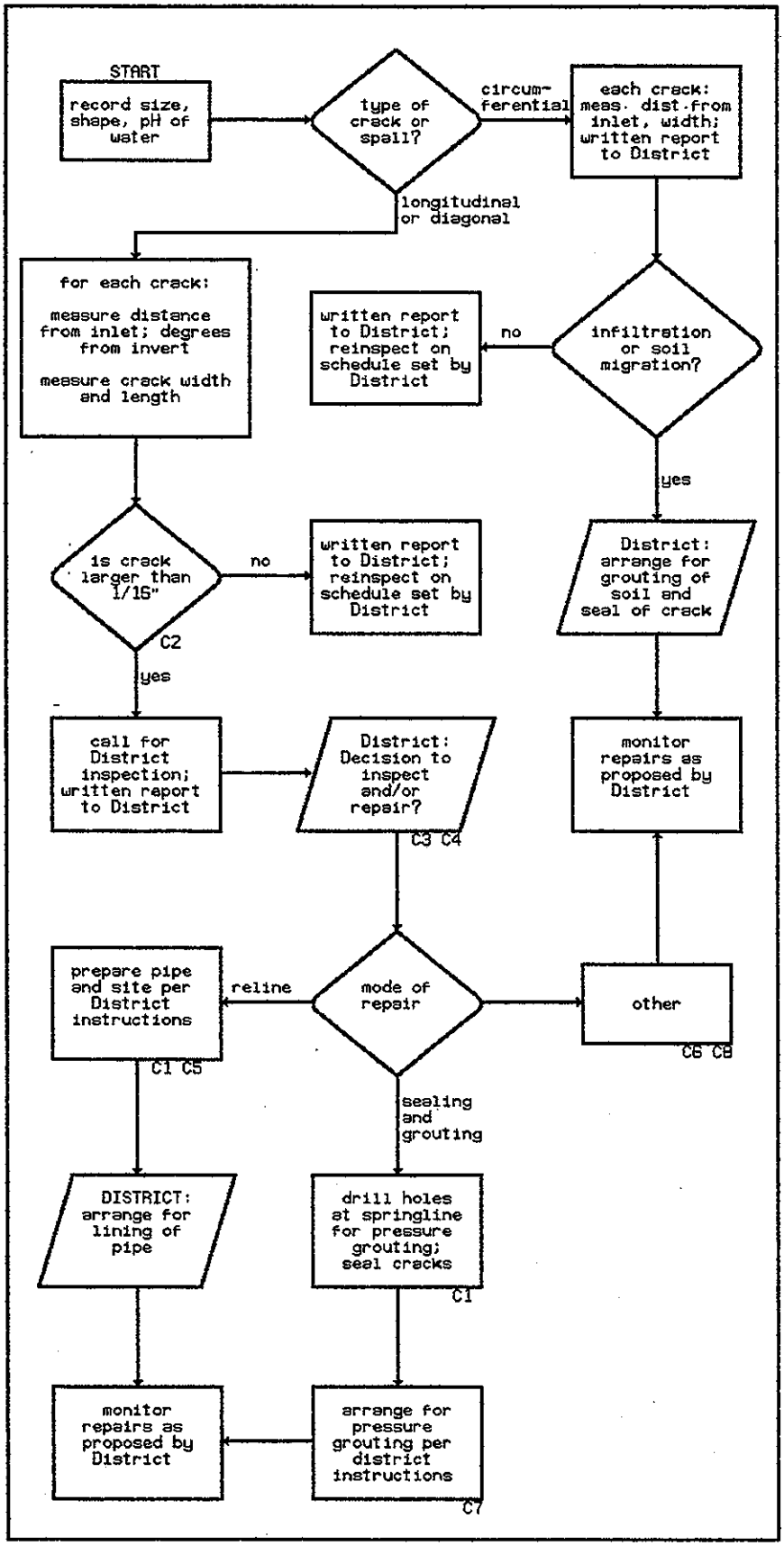
COMMENTS:

C1. Diversion of stream may require passage of fish.

C2. May require redesign of channel for fish migration.

C3. Piping may result in serious structural failure and/or embankment instability.

C4. Bituminous, resin and other coatings have to satisfy fire, safety, and environmental standards and/or requirements. See Part II;1;1.7-10 for alternatives.



UNREINFORCED CONCRETE:

CRACKS AND SPALLS

GENERAL NOTES:

Unreinforced concrete pipe culverts of the cast in place type, wherein the side and bottom forms for the casting of the concrete are the earth walls and bottom, depends upon the passive lateral restraint at springline for proper structural performance. With such restraint, the cross section is a highly redundant structure capable of minimizing bending stresses in favor of compression within the wall of the concrete. Hairline cracking (less than 1/16") is evidence of a "pin" developing and does not effect the stability of the structure. NEVER DIG A TEST PIT TO EXAMINE THE CONDITION OF THE WALL FROM WITHOUT! Such removal of the passive restraint could lead to structural problems. See comment C4, below.

COMMENTS:

C1. Diversion of stream may require passage of fish.

C2. Check with District for size of critical crack width.

C3. Careful inspection should include attention to any fill or bedding material transported within or without the pipe.

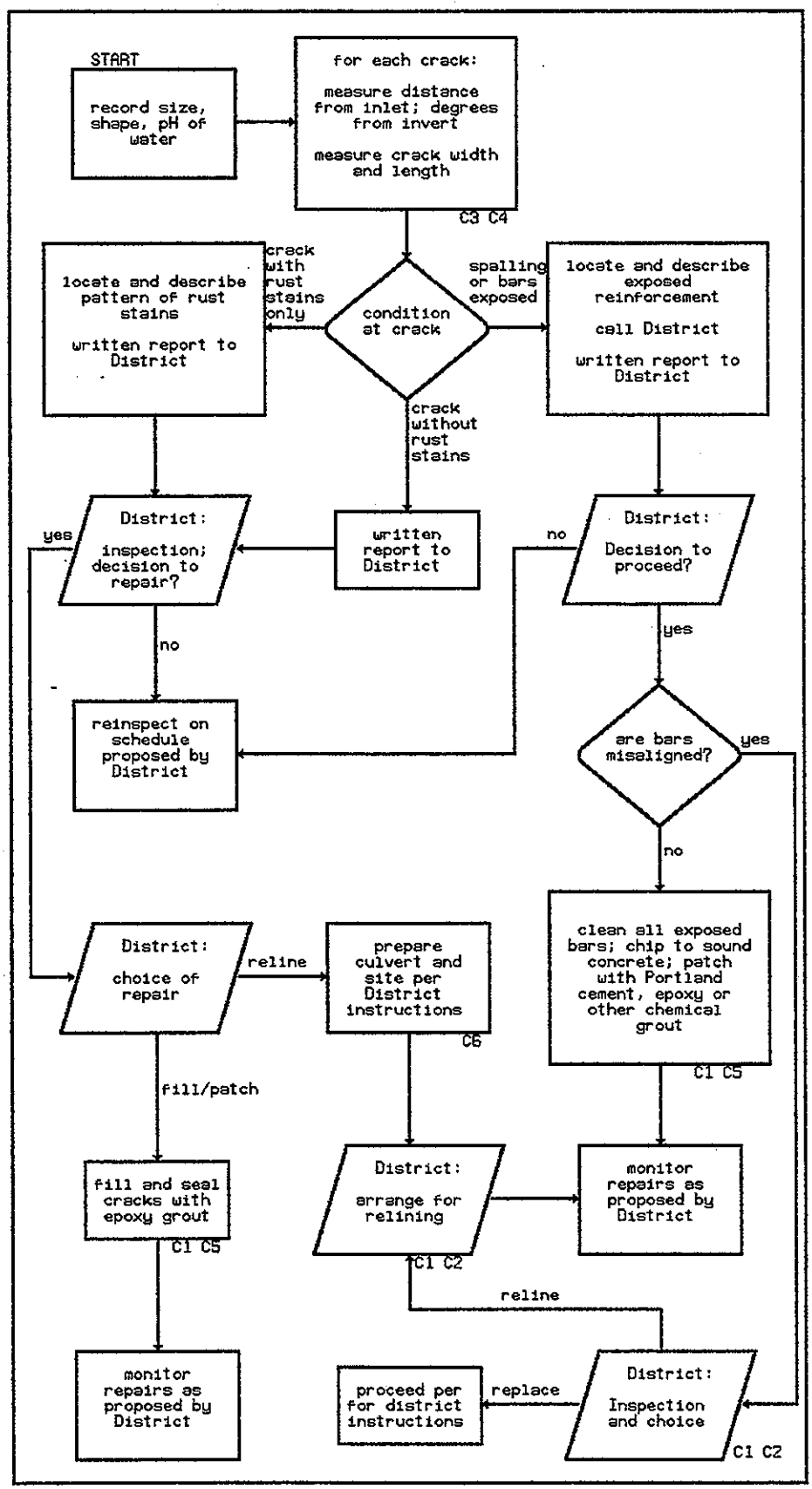
C4. If cracks greater than 1/16" appear at both crown and invert, inspection should include a mapping of the cross sectional inner surface, the geometry of which will be useful to determine whether there is significant cracking of the outer wall at springline. See General Notes above.

C5. Should an outside sliplining contractor be engaged, it is important to receive the contractor's instructions for site requirements, including required working space.

C6. Resin and other coatings have to satisfy fire, safety, and environmental standards and/or requirements.

C7. For details of grouting procedures for Portland cement, epoxy and other chemical grouts, see Part II;1.2.2-4.

C8. For installation details for flexible sealant see Part II;1.2.1.



REINFORCED CONCRETE:

CRACKS AND SPALLS

GENERAL NOTES:

Although bond between the reinforcing bars and the concrete may be broken before any exposure of the bar, or spalling of the concrete, there is no question that bond is absent when those effects are noticed. This has very serious structural implications in that such steel that was designed to carry internal forces resisting earth and live loads is no longer functioning as intended. The concrete alone should never be assumed to be capable of carrying the noted loads.

COMMENTS:

C1. Diversion of stream may require passage of fish.

C2. May require redesign of channel for fish migration.

C3. Cracks and spalls at crown or invert, in a reinforced concrete pipe are of special significance and imply a stuctural deterioration. It may be necessary to remove transported or caked material from invert, and to lightly dampen invert in order to discover cracks.

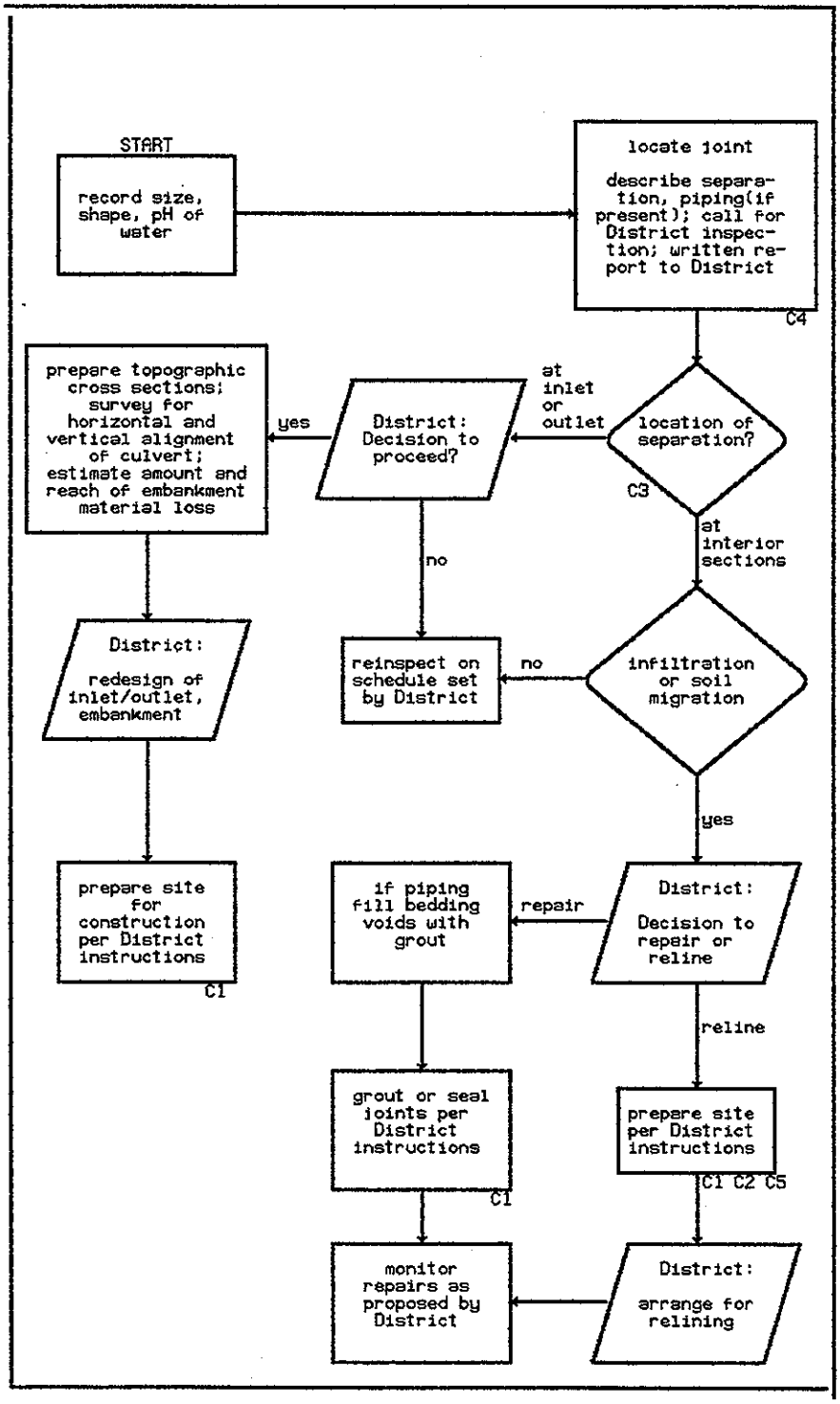
C4. The mapping of all diagonal cracks should clearly locate the beginning and end points.

C5. For details of grouting procedures, see Part II;1.2.2-3.

C6. Should an outside sliplining contractor be engaged, it is important to receive the contractor's instructions for site requirements.

PRECAST CONCRETE:

JOINT SEPARATION



GENERAL NOTES:

Joint separations of a concrete culvert from its inlet outlet structure may be expected to lead to embankment washout and failure. High cost associated with such failures.

COMMENTS:

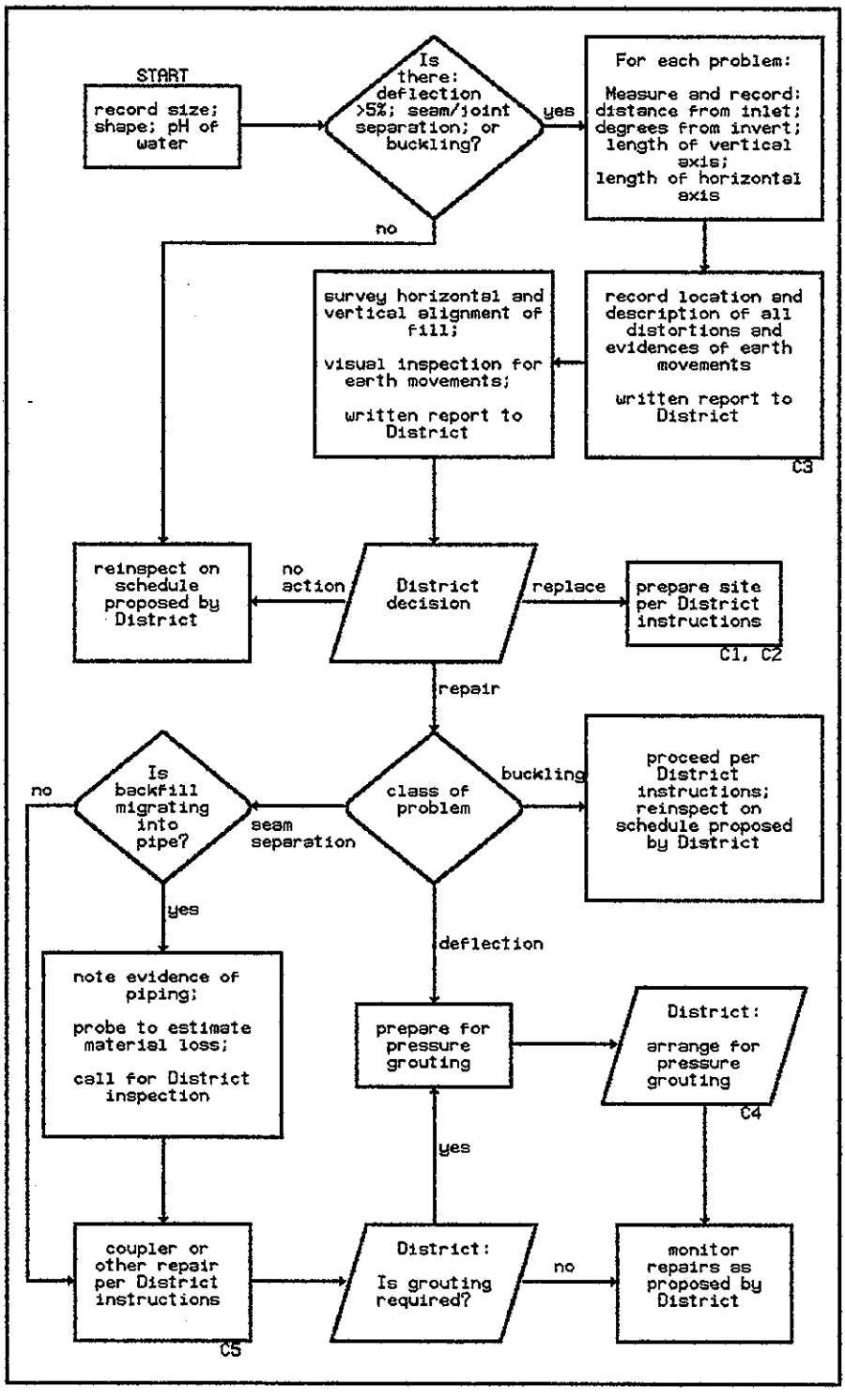
C1. Diversion of stream may require passage of fish.

C2. May require redesign of channel for fish migration.

C3. Separation of inlet or outlet from main body of culvert may lead to very significant structural failure.

C4. Piping may result in serious structural failure and/or embankment instability.

C5. Should an outside sliplining contractor be engaged, it is important to receive the contractor's instructions for site requirements, including required working space.



METAL OR PLASTIC:

STRUCTURAL PROBLEMS

GENERAL NOTES:

The District may want to contact the manufacturer of the culvert if structural problems associated with buckling, seam separation or excessive deflection appear. An engineering representative of the manufacturer should be consulted if structual problems are judged to be serious and/or are continuing to progress.

COMMENTS:

C1. Diversion of stream may require passage of fish.

C2. May require redesign of channel for fish migration.

C3. Include full description of combined effects if such be present.

C4. The pressure associated with grouting the soil at springline should not be more than that required to assure the development of passive soil restraint.

C5. See joint repair instructions, Part II;1.3.1-2.

APPENDIX C

ECONOMIC ANALYSIS WORK SHEET

(See pg ___ Part ____ of report)

Alternatives being considered are:

1. _____
2. _____
3. _____
4. _____

Discount rate used by District is: i = _____

Analysis period (required life of culvert) is: N = _____

Note: N may be forever (N = ∞)

Is N > 20 years YES _____ GO TO A

NO _____ GO TO B

A. Long Analysis Period

Alternative Number	1	2	3	4
Initial Cost (I)				
Expected life (n)				
(A/p, i, n)*				

EUAC** = I (A/p, i, n)

Strategy with lowest EUAC is _____

$$*(A/p,\ i,\ n) = \frac{i\ (1+i)^n}{(1+i)^n - 1}$$

**Equivalent Uniform Annual Cost

B. Short Analysis Period

Alternative Number	1	2	3	4
Initial Cost (I)				
Expected life (n)				
(P/F, i, n)*				
(P/F, i, 2n) (if 2n < N)				
(P/F, i, 3n) (if 3n < N)				

PWC** (= I + I (P/F, i, n) +...)
[Include additional terms only if
xn < N where x = 2, 3, etc.]

Strategy with lowest PWC is _____

$$*(P/F,\ i,\ n) = \frac{1}{(1+i)^n}$$

** Present Worth of Cost

Note: This analysis results in selection of the best strategy for the long term. The user should also consider budgetary constraints which may indicate selection of a strategy with low first cost.