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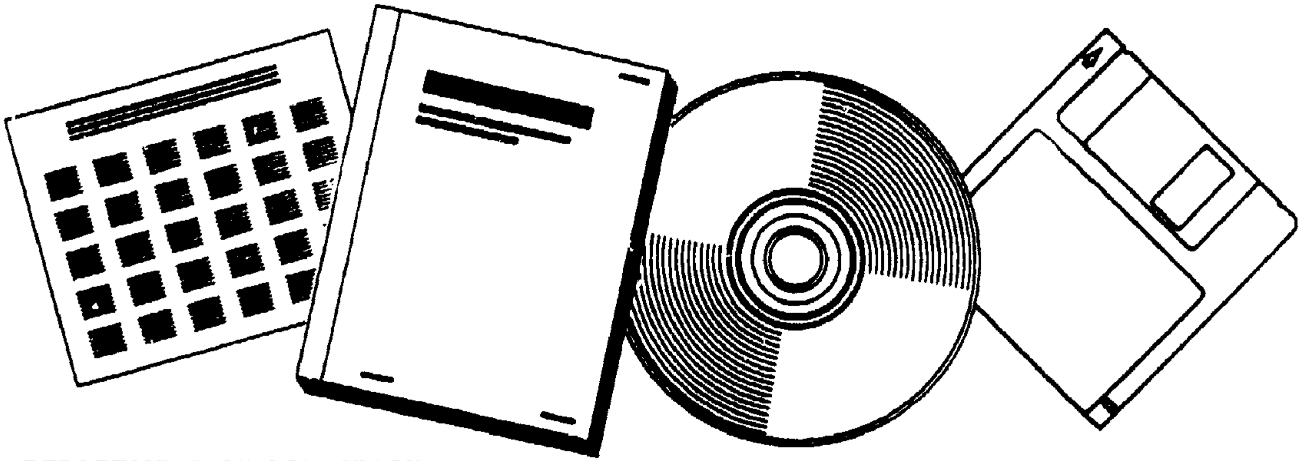
CULVERT REPAIR PRACTICES MANUAL. VOLUME 2 (APPENDICES)

SMITH (WILBUR) ASSOCIATES, FALLS CHURCH, VA

MAY 95



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Culvert Repair Practices Manual

Volume II

U.S. Department of Transportation
Federal Highway Administration

Research and Development
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

FOREWORD

The *Culvert Repair Practices Manual* was designed to supplement the *Culvert Inspection Manual* developed by the Federal Highway Administration in 1986. The *Culvert Repair Practices Manual* provides a compendium of rehabilitation techniques to be used when inspections show the need to repair a culvert. Volume I consists of the text. Volume II presents Appendixes.

Culverts, like pavements, are generally classified into two groups: rigid and flexible. Concrete is typically used in rigid culverts; steel and aluminum are primary materials that comprise flexible ~~systems. The *Culvert Repair Practices Manual* provides resource information on all culvert types,~~ the materials used in their fabrication, and the construction methods used in their placement. It outlines the causes of common deterioration problems and methods for maintenance and repair. It also includes guidance for deciding whether a culvert should be repaired or replaced.

This manual is designed for a broad audience. Recognizing that some states assign responsibility of culvert repair to maintenance departments while others assign it to bridge sections or other departments, the authors have designed the manual for all design, construction, and maintenance staff who are involved in the construction of culverts. Those responsible for the design and engineering of new culverts may also find the information useful.

Byron N. Lord

for Charles J. Nemmers
Director, Office of Engineering and
Highway Operations Research and Development

NOTICE

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16. Abstract

All culverts with openings of more than 20 ft, measured parallel to the roadway, must be inspected on a two-year cycle in accordance with the National Bridge Inspection Standards (NBIS). Many highway agencies also inspect smaller culverts on the same cycle. The NBIS, and prudent engineering, requires that culverts that are structurally weak or hydraulically inadequate be inspected on a more frequent cycle.

This manual has been developed to provide guidance to highway agencies on procedures that may be used to repair a wide variety of types of problems that beset metal and concrete culverts of all types. Many of the procedures are also applicable to the repair of timber and stone masonry culverts. Procedures are also presented on ways to improve the inlet and outlet ends of culverts as well as the streambed channels leading to and from them.

Information presented in this manual has been compiled from numerous contacts with representatives of the culvert industry as well as many highway agencies through the United States and Canada.

This is a two-volume report. Volume I consists of the text. Volume II presents Appendixes.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in²	square inches	645.2	square millimeters	mm²
ft²	square feet	0.093	square meters	m²
yd²	square yards	0.836	square meters	m²
ac	acres	0.405	hectares	ha
mi²	square miles	2.59	square kilometers	km²
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft³	cubic feet	0.028	cubic meters	m³
yd³	cubic yards	0.765	cubic meters	m³
NOTE: Volumes greater than 1000 l shall be shown in m³.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m²	cd/m²
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in²	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm²	square millimeters	0.0016	square inches	in²
m²	square meters	10.764	square feet	ft²
m²	square meters	1.195	square yards	yd²
ha	hectares	2.47	acres	ac
km²	square kilometers	0.386	square miles	mi²
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m³	cubic meters	35.71	cubic feet	ft³
m³	cubic meters	1.307	cubic yards	yd³
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m²	candela/m²	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in²

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised September 1993)

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GLOSSARY OF TERMS

Abrasion:	Wearing or grinding away of material by water laden with sand, gravel, or stones.
Acidic:	Substances with a pH less than 7.0 which may react with or corrode certain metals. Soils or water may be acidic and react with metal culverts.
Aggradation:	General and progressive raising of the streambed by deposition of sediment.
Aggressive Environment:	A soil-stream environment where corrosion-abrasion deterioration is highly destructive to culvert life.
Alkaline:	Substances having a pH greater than 7.0. Such substances are caustic or able to corrode or dissolve materials. Mineral salts found in arid soils are alkaline.
Allowable Headwater:	Difference in elevation between the flowline of the culvert and the lowest point at which the water surface upstream would either flood the roadway or jeopardize property.
Anode:	A metallic surface on which oxidation occurs, giving up electrons with metal ions going into solution or forming an insoluble compound of the metal.
Autogeneous Healing:	A process where small cracks are healed by exposure to moisture, forming calcium carbonate crystals that accumulate along the crack edges, inter-twining and building until the crack is filled.
Backfill:	The material used to refill the trench or the embankment placed over the top of the bedding and culvert.
Backwater:	The water upstream from an obstruction in which the free surface is elevated above the normal water surface profile.

Bedding:	The soil used to support the load on the pipe. For rigid pipe, the bedding distributes the load over the foundation. It does the same thing for flexible pipe except that it is not as important a design factor.
Bed Load:	Sediment that is transported in a stream by rolling, sliding, or skipping along the bed or very close to it; considered to be within the bed layer.
Bituminous (Coating):	Of or containing bitumen, as asphalt or tar.
Box Section:	A concrete or corrugated pipe with a rectangular or nearly rectangular cross section.
Buckling:	Failure by an inelastic change in alignment (usually as a result of compression)
Buried Pipe:	A structure that incorporates both the properties of the pipe and the properties of the soil surrounding the pipe.
Buoyancy:	The upward force exerted by a fluid on a body in it; the tendency to float an empty pipe (by exterior hydraulic pressure).
Capacity:	Maximum flow rate that a channel, conduit, or structure is hydraulically capable of carrying. The units are usually CFS or GPM.
Cathode:	A surface that accepts electrons and does not corrode.
Cathodic Protection:	A means of preventing metal from eroding. This is done by making the metal a cathode through the use of impressed direct current or by attaching a sacrificial anode.
Cavitation:	A phenomenon associated with the vaporization of a flowing liquid at high velocities in a zone of low pressure, wherein cavities filled with liquid (vapor bubbles) alternately develop and collapse; surface pitting of a culvert may result.

Cement Mortar Lining:	Cement mortar grout centrifugally applied to the interior of existing culverts. Grout is applied after cleaning the existing pipe to protect the pipe and maintain capacity.
CFS:	Rate of flow in cubic feet per second.
Chlorides:	Binary chemical compounds containing chlorine which can corrode concrete reinforcing steel.
Cladding:	Aluminum culvert sheet sandwich with aluminum magnesium - manganese alloy 3004 between two layers of aluminum - zinc alloy 7072 cladding for corrosion protection.
Class:	The grade or quality of pipe.
Coating:	Any material used to protect the integrity of the structural elements of a pipe from the environment and add service life to the culvert.
Compaction:	The process by which a sufficient amount of energy is applied to soil to achieve a specific density.
Conductivity:	A measure of the corrosive potential of soils which is expressed in milli-mhos per centimeter. It is the reciprocal of resistivity.
Conductor:	A metallic connection (in drainage facilities, usually the pipe itself) that permits electrical current flow by completing the circuit.
Conduit:	Usually a pipe, designed to flow according to open channel equations.
Corrosion:	Deterioration or dissolution of a material by chemical or electrochemical reaction with its environment.
Cover:	The depth of backfill over the top of the pipe.
Crack:	A fissure in an installed precast concrete culvert.

Critical Depth:	Critical depth is the depth at which the specific energy of a given flow rate is at a minimum. For a given discharge and cross-section geometry, there is only one critical depth.
Critical Flow:	That flow in open channels or conduits at which the energy content of the fluid is at a minimum.
Crown:	The crown is the inside top of the culvert.
Culvert:	A culvert is defined as the following: A structure that is usually designed hydraulically to take advantage of submergence to increase hydraulic capacity; a structure used to convey surface runoff through embankment; a structure, as distinguished from bridges, that is usually covered with embankment and is composed of structural material around the entire perimeter, although some are supported on spread footings with the streambed serving as the bottom of the culvert; and a structure that is 20 feet or less in centerline length between extreme ends of openings for multiple.
Debris:	Any material including floating woody materials and other trash, suspended sediment, or bed load, moved by a flowing stream.
Deflection:	Change in the original or specified inside diameter of pipe.
Degradation:	General progressive lowering of the stream channel by erosion.
Discharge (Q):	Flow from a culvert, sewer, or channel in cubic feet per second (CFS).
Drainage:	Interception and removal of ground water or surface water by artificial or natural means.
Drop Inlet:	A type of inlet structure which conveys the water from a higher elevation to a lower outlet elevation smoothly without a free fall at the discharge.

Durability:	Ability to withstand corrosion and abrasion over time or service life.
Electrolyte:	Moisture or a liquid carrying ionic current between two metal surfaces, the anode and the cathode.
Embankment:	A bank of earth, rock or material constructed above the natural ground surface over a culvert.
End Section:	A concrete or steel appurtenance attached to the end of a culvert for the purpose of hydraulic efficiency and anchorage.
Energy Dissipator:	Device to decrease hydraulic energy placed in ditches or culvert outfalls to reduce streambed scour.
Energy Gradient:	The increase or decrease in total energy of flow with respect to distance along the channel.
Energy Grade Line:	The line which represents the total energy gradient along the channel. It is established by adding together the potential energy expressed as the water surface elevation referenced to a datum and the kinetic energy (usually expressed as velocity head) at points along the streambed or channel floor.
Erosion (Culvert):	Wearing or grinding away of culvert material by water laden with sand, gravel, or stones; generally referred to as abrasion.
Erosion (Stream):	Wearing away of the streambed by flowing water.
Female End of Pipe (bell, socket, groove, modified groove):	That portion of the end of the pipe, regardless of its shape, size, or dimensions, which overlaps a portion of the end of the adjoining pipe.
Fish Passage:	Ability of native trout and anadromous fish to pass through bridge and culvert structures.
Flexible Pipe:	A pipe with relatively little resistance to bending. As the load increases, the vertical diameter decreases and the horizontal diameter increases, which is resisted by the soil around the pipe.

Flood Frequency:	The number of years, on the average, within which a given discharge will be equaled or exceeded.
Flow Line:	A line formed by the inverts of pipe.
Foundation:	The in place material beneath the pipe.
Free Outlet:	A free outlet has a tailwater equal to or lower than critical depth. For culverts having free outlets, lowering of the tailwater has no effect on the discharge or the backwater profile upstream of the tailwater.
Galvanizing:	Application of a thin layer of zinc to steel by hot-dipping.
Gauge:	Thickness of sheet metal used in corrugated metal pipe.
GPM:	Gallons per minute.
Grade:	The longitudinal slope of the channel as a ratio of the drop in elevation to the distance.
Gradient:	See grade.
Groundwater:	Water contained in the subsoil which is free to move either vertically or horizontally.
Hairline Cracks:	Very small cracks that form in the surface of the concrete pipe due to tension caused by loading.
Holidays:	Defect in protective coating on metal surface.
Haunches:	The outside areas of a pipe between the spring line and the bottom of the pipe.
Head (Static):	The heights of water above any plane or point of reference.
Headloss:	The loss of energy reported in feet of head.
Headwall:	A concrete structure placed at the inlet and outlet of a culvert to protect the embankment slopes, anchor the culvert, and prevent undercutting.

Headwater:	The distance between the flowline elevation at the inlet of a culvert and the water surface at the inlet.
Hydraulics:	The mechanics of fluids, primarily water.
Hydraulic Gradeline:	An imaginary line, representing the total energy and paralleling the free water surface if the flow were at atmospheric pressure.
Hydraulic Jump:	An abrupt rise in the water surface in the direction of flow when the type of flow changes from supercritical to subcritical.
Hydraulic Radius:	The cross-sectional area of flow divided by the length of that part of its periphery in contact with its containing conduit; the ratio of area to wetted perimeter.
Hydrology:	The science of water related to its properties and distribution in the atmosphere, on the land surface, and beneath the surface of the land.
Improved Inlet:	An improved inlet has an entrance geometry that decreases the flow constriction at the inlet and thus increases the capacity of culverts. These inlets are referred to as either side- or slope-tapered (walls or bottom tapered).
Impingement:	Suspended solid particles or gas bubbles in water striking the surface or turbulence alone breaking down the protective layer of a metal or concrete surface.
Insertion Renewal:	General term for relining or sliplining.
Inversion Lining:	Process of inverting pliable tube into existing pipe with hydrostatic or air pressure to reline existing pipe. The liner is forced against the existing pipe and bonded with thermosetting resins to provide structural strength and improved smoothness.
Invert:	The invert is the flowline of the culvert (inside bottom), of the transverse cross section of a pipe.
Joint:	A connection between two pipe sections made either with or without the use of additional parts.

Link Pipe Lining:	Method of pulling a short, folded pipe line segment to the damaged point in an existing pipe and jacking the segment into place.
Long Span Culverts:	Culverts that are designed on structural aspects rather than hydraulic considerations. Usually constructed of structural plate which exceed defined sizes for pipes, pipe arches, or arches or may be special shapes that involve a long radius of curvature in the crown or side plates.
Male End of Pipe (Spigot, Tongue, Modified Tongue):	That portion of the end of the pipe, regardless of its shape or dimensions, which is overlapped by a portion of the end of the adjoining pipe.
Manning's Equation:	An equation for the empirical relationship used to calculate the barrel friction loss in culvert design.
Metal Corrosion:	An electrical process involving an electrolyte (moisture), an anode (the metallic surface where oxidation occurs), a cathode (the metallic surface that accepts electrons and does not corrode), and a conductor (the metal pipe itself).
Minor Head Losses:	Head lost through transitions such as entrances, outlets, obstructions, and bends.
Normal Flow:	Normal flow occurs in a channel reach when the discharge, velocity and depth of flow do not change throughout the reach. The water surface profile and channel bottom slope will be parallel. This type of flow will exist in a culvert operating on a steep slope provided the culvert is sufficiently long.
O-Ring Gasket:	A solid gasket of circular cross section. Used in joint connections.
Outfall:	In hydraulics, the discharge end of drains or sewers. Also referred to as outlet.
Outlet:	See Outfall.

Oxidation-Reduction potential:	Used as a primary indicator of anaerobic bacterial corrosion which occurs in wet, poorly drained soils at the soil-metal interface. Iron in aerated water in the presence of sulfate-reducing bacteria corrodes at an accelerated rate. Also known as the "redox potential."
Perforation:	Complete penetration of metal culvert that generally occurs in the invert.
pH Value:	The log of the reciprocal of the hydrogen ion concentration of a solution. A pH value of 7.0 is neutral; values of less than 7.0 are acid; values of more than 7.0 are alkaline.
Pipe:	A tube or conduit.
Pipe Diameter:	The inside diameter of a pipe.
Piping:	A process of subsurface erosion in which surface runoff flows along the outside of a culvert and with sufficient hydraulic gradient erodes and carries away soil around or beneath the culvert.
Polyethylene Pipe:	Plastic pipe manufactured from polymerized ethylene in corrugated or smooth configurations of various dimensions.
Polymer Coating:	Protective coatings of plastic polymer resins with other materials.
Ponding:	Water back up in a channel or ditch as the result of a culvert of inadequate capacity or design to permit the water to flow unrestricted.
Prestressed Concrete:	Concrete that is continually under a compressive stress that is created when the steel reinforcing bars, wires, or cables are held in a stretched condition during placing of the plastic concrete and until the concrete has hardened. The pull on the reinforcing steel is then released providing additional strength.
Reinforced Concrete Pipe:	A concrete pipe designed with reinforcement as a composite structure.

Rigid Pipe:	A pipe with a high resistance to bending
Rip Rap:	Rough stone of various sizes placed compactly or irregularly to prevent scour by water or debris.
Roughness Coefficient (n):	A factor in the Kutter, Manning, and other flow formulas representing the effect of channel (or conduit) roughness upon energy losses in flowing water. It is based on either hydraulic test results or calculated using theoretical relationships.
Resistivity (Soil):	An electrical measurement in ohm-cm, which is one of the factors for estimating the corrosivity of a given soil to metals.
Runoff:	That part of precipitation carried off from the area upon which it falls.
Sacrificial Coating:	A coating over the base material to provide protection to the base material. Examples include galvanizing on steel and cladding on aluminum.
Sacrificial Thickness:	Additional pipe thickness provided for extra service life of the culvert in an aggressive environment.
Scour (Outlet):	Degradation of the channel at the culvert outlet as a result of erosive velocities.
Seepage:	The escape of water through the soil, or water flowing from a fairly large area of soil instead of from one spot, as in the case of a spring.
Shotcrete Lining:	Application of pneumatically applied cement plaster or concrete to an in place structure to increase structural strength and improve the surface smoothness.
Skew (Skew Angle):	The acute angle formed by the intersection of the line normal to the centerline of the road with the centerline of a culvert or other structure.

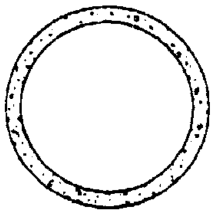
Slabbing:	Radial tension failure of concrete pipe resulting from the tendency of curved reinforcing steel or cage to straighten out under load. It is characterized by large slabs of concrete "peeling" away from the sides of the pipe.
Slide:	Movement of a part of the earth (embankment) under the force of gravity.
Sliplining:	The process of placing a smaller diameter pipe in a larger diameter existing pipe to improve the culvert structure and repair leaks. The annular space between the pipes is usually filled with grout.
Slope:	Steep slope occurs where the critical depth is greater than the normal depth. Mild slope occurs where critical depth is less than normal depth.
Spelter:	Zinc slabs or plates.
Spalling (Culvert):	The separation of surface concrete due to fractures in the concrete parallel or slightly inclined to the surface of the concrete.
Springline:	The points on the internal surface of the transverse cross section of a pipe intersected by the line of maximum horizontal dimension; or in box sections, the mid-height of the internal vertical wall.
Structural Plate:	Plates of structural steel used to fabricate large culvert structures such as arches or boxes.
Submerged Inlet:	A submerged inlet occurs where the headwater is greater than 1.2D.
Submerged Outlet:	A submerged outlet occurs where the tailwater elevation is higher than the crown of the culvert.
Sulfates:	Chemical compounds containing SO found in alkaline soils that cause concrete deterioration.
Suspended Load:	Sediment that is supported by the upward components of the turbulent currents in a stream.

Tailwater Depth:	The depth of water just downstream from a structure.
Velocity Head:	For water moving at a given velocity, the equivalent head through which it would have to fall by gravity to acquire the same velocity.
Wall (Concrete Pipe):	The structural element composed of concrete or concrete and reinforcing steel between the inside and outside of a concrete pipe.
Watercourse:	A channel in which a flow of water occurs, either continuously or intermittently, with some degree of regularity.
Watershed:	Region or area contributing to the supply of a stream or lake, drainage area, drainage basin, or catchment area.
Weir:	A man made barrier in an open channel over which water flows. It is used to measure the quantity of flow.
Wetted Perimeter:	The length of the wetted contact between the water and the containing conduit measured at right angles to the conduit.

APPENDIX A. STANDARD SIZES AND GEOMETRIC DATA FOR PIPE

STANDARD SIZES FOR CONCRETE PIPE

CIRCULAR PIPE



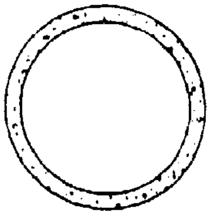
ASTM C 14—Nonreinforced Sewer and Culvert Pipe, Bell and Spigot Joint

Internal Diameter, inches	Class 1		Class 2		Class 3	
	Minimum Wall Thickness, inches	Approx. Weight, pounds per foot	Minimum Wall Thickness, inches	Approx. Weight, pounds per foot	Minimum Wall Thickness, inches	Approx. Weight, pounds per foot
4	5/8	9.5	3/4	13	3/4	13
6	5/8	17	3/4	20	7/8	21
8	3/4	27	7/8	31	1-1/8	36
10	7/8	37	1	42	1-1/4	50
12	1	50	1-3/8	68	1-3/4	90
15	1-1/4	78	1-5/8	100	1-7/8	120
18	1-1/2	105	2	155	2-1/4	165
21	1-3/4	159	2-1/4	205	2-3/4	260
24	2-1/8	200	3	315	3-3/4	350
27	3-1/4	390	4	450	4-7/8	450
30	3-1/2	450	4-1/4	540	4-1/4	540
33	3-3/4	520	4-1/2	620	4-1/2	620
36	4	580	4-3/4	700	4-3/4	700

SOURCE : AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES FOR CONCRETE PIPE

**CIRCULAR
PIPE**



ASTM C76–Reinforced Concrete Culvert, Storm Drain and Sewer Pipe, Bell and Spigot Joint.				
Internal Diameter, inches	Wall A		Wall B	
	Minimum Wall Thickness, inches	Approximate Weight, pounds per foot	Minimum Wall Thickness, inches	Approximate Weight, pounds per foot
12	1-3/4	90	2	106
15	1-7/8	120	2-1/4	148
18	2	155	2-1/2	200
21	2-1/4	205	2-3/4	260
24	2-1/2	265	3	325
27	2-5/8	310	3-1/4	388
30	2-3/4	363	3-1/2	459

These tables are based on concrete weighing 150 pounds per cubic foot and will vary with heavier or lighter weight concrete.

SOURCE : AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES FOR CONCRETE PIPE

ASTM C 76 – Reinforced Concrete Culvert, Storm Drain and Sewer Pipe, Tongue and Groove Joints

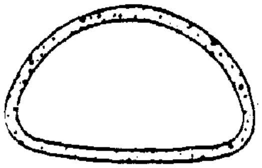
Internal Diameter, inches	Wall A		Wall B		Wall C	
	Minimum Wall Thickness, inches	Approx Weight, pounds per foot	Minimum Wall Thickness, inches	Approx Weight, pounds per foot	Minimum Wall Thickness, inches	Approx Weight, pounds per foot
12	1-3/4	79	2	93	2-3/4	133
15	1-7/8	103	2-1/4	127	3	177
18	2	131	2-1/2	168	3-1/4	225
21	2-1/4	171	2-3/4	214	3-1/2	279
24	2-1/2	217	3	264	3-3/4	366
27	2-5/8	255	3-1/4	322	4	420
30	2-3/4	295	3-1/2	384	4-1/4	476
33	2-7/8	336	3-3/4	451	4-1/2	552
36	3	383	4	524	4-3/4	654
42	3-1/2	520	4-1/2	686	5-1/4	811
48	4	683	5	867	5-3/4	1011
54	4-1/2	864	5-1/2	1068	6-1/4	1208
60	5	1064	6	1295	6-3/4	1473
66	5-1/2	1287	6-1/2	1542	7-1/4	1735
72	6	1532	7	1811	7-3/4	2015
78	6-1/2	1797	7-1/2	2100	8-1/4	2410
84	7	2085	8	2409	8-3/4	2660
90	7-1/2	2395	8-1/2	2740	9-1/4	3020
96	8	2710	9	3090	9-3/4	3355
102	8-1/2	3078	9-1/2	3480	10-1/4	3760
108	9	3446	10	3865	10-3/4	4160
114	9-1/2	3840	10-1/2	4278	11-1/4	4611
120	10	4263	11	4716	11-3/4	5066
126	10-1/2	4690	11-1/2	5175	12-1/4	5542
132	11	5148	12	5655	12-3/4	6040
138	11-1/2	5627	12-1/2	6156	13-1/4	6558
144	12	6126	13	6679	13-3/4	7098
150	12-1/2	6647	13-1/2	7223	14-1/4	7659
156	13	7190	14	7789	14-3/4	8242
162	13-1/2	7754	14-1/2	8375	15-1/4	8846
168	14	8339	15	8983	15-3/4	9471
174	14-1/2	8945	15-1/2	9612	16-1/4	10,117
180	15	9572	16	10,263	16-3/4	10,785

These tables are based on concrete weighing 150 pounds per cubic foot and will vary with heavier or lighter weight concrete.

SOURCE : AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES FOR CONCRETE PIPE

ARCH PIPE



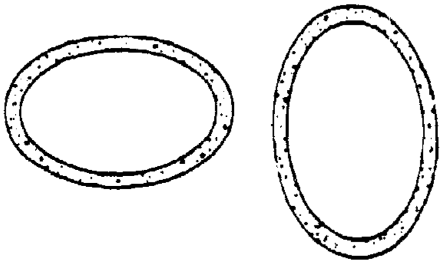
DIMENSIONS AND APPROXIMATE WEIGHTS OF CONCRETE ARCH PIPE

ASTM C 506 – Reinforced Concrete Arch Culvert, Storm Drain and Sewer Pipe					
Equivalent Round Size, inches	Minimum Rise inches	Minimum Span, inches	Minimum Wall Thickness inches	Water Way Area square feet	Approximate Weight pounds per foot
15	11	18	2¼	1.1	114
18	13½	22	2½	1.65	170
21	15½	26	2¾	2.2	225
24	18	28½	3	2.8	320
30	22½	36¼	3½	4.4	450
36	26⅝	43¾	4	6.4	595
42	31 11/16	51⅛	4½	8.8	740
48	36	58½	5	11.4	880
54	40	65	5½	14.3	1090
60	45	73	6	17.7	1320
72	54	88	7	25.6	1840
84	62	102	8	34.6	2520
90	72	115	8½	44.5	2750
96	77¼	122	9	51.7	3110
108	87⅛	138	10	66.0	3850
120	96⅛	154	11	81.8	5040
132	106½	168¾	10	99.1	5220

SOURCE : AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES FOR CONCRETE PIPE

HORIZONTAL
AND
VERTICAL
ELLIPSE
PIPE



DIMENSIONS AND APPROXIMATE WEIGHTS OF ELLIPTICAL CONCRETE PIPE

ASTM C 507 – Reinforced Concrete Elliptical Culvert, Storm Drain and Sewer Pipe

Equivalent Round Size, inches	Minor Axis, inches	Major Axis, inches	Minimum Wall Thickness, inches	Water-Way Area, square feet	Approximate Weight, pounds per foot
18	14	23	2¾	1.8	195
24	19	30	3¼	3.3	300
27	22	34	3½	4.1	365
30	24	38	3¾	5.1	430
33	27	42	3¾	6.3	475
36	29	45	4½	7.4	625
39	32	49	4¾	8.8	720
42	34	53	5	10.2	815
48	38	60	5½	12.9	1000
54	43	68	6	16.6	1235
60	48	76	6½	20.5	1475
66	53	83	7	24.8	1745
72	58	91	7½	29.5	2040
78	63	98	8	34.6	2350
84	68	106	8½	40.1	2680
90	72	113	9	46.1	3050
96	77	121	9½	52.4	3420
102	82	126	9¾	59.2	3725
108	87	136	10	66.4	4050
114	92	143	10½	74.0	4470
120	97	151	11	82.0	4930
132	106	166	12	99.2	5900
144	116	180	13	118.6	7000

SOURCE : AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES FOR CONCRETE PIPE

DIMENSIONS AND APPROXIMATE WEIGHTS OF CONCRETE BOX SECTIONS

ASTM C789–PRECAST REINFORCED CONCRETE BOX SECTIONS						
		Thickness (in.)			Waterway Area (Sq. Feet)	Approx. Weight (lbs/ft)
Span (Ft.)	Rise (Ft.)	Top Slab	Bot. Slab	Wall		
3	2	4	4	4	5.8	600
3	3	4	4	4	8.8	700
4	2	5	5	5	7.7	910
4	3	5	5	5	11.7	1030
4	4	5	5	5	15.7	1160
5	3	6	6	6	14.5	1430
5	4	6	6	6	19.5	1580
5	5	6	6	6	24.5	1730
6	3	7	7	7	17.3	1880
6	4	7	7	7	23.3	2060
6	5	7	7	7	29.3	2230
6	6	7	7	7	35.3	2410
7	4	8	8	8	27.1	2600
7	5	8	8	8	34.1	2800
7	6	8	8	8	41.1	3000
7	7	8	8	8	48.1	3200
8	4	8	8	8	31.1	2800
8	5	8	8	8	39.1	3000
8	6	8	8	8	47.1	3200
8	7	8	8	8	55.1	3400
8	8	8	8	8	63.1	3600
9	5	9	9	9	43.9	3660
9	6	9	9	9	52.9	3880
9	7	9	9	9	61.9	4110
9	8	9	9	9	70.9	4330
9	9	9	9	9	79.9	4560
10	5	10	10	10	48.6	4380
10	6	10	10	10	58.6	4630
10	7	10	10	10	68.6	4880
10	8	10	10	10	78.6	5130
10	9	10	10	10	88.6	5380
10	10	10	10	10	98.6	5630
11	4	11	11	11	42.3	4880
11	6	11	11	11	64.3	5430
11	8	11	11	11	86.3	5980
11	10	11	11	11	108.3	6530
11	11	11	11	11	119.3	6810
12	4	12	12	12	46.0	5700
12	6	12	12	12	70.0	6300
12	8	12	12	12	94.5	6900
12	10	12	12	12	118.0	7500
12	12	12	12	12	142.0	8100

ASTM C850–PRECAST REINFORCED CONCRETE BOX SECTIONS						
		Thickness (in.)			Waterway Area (Sq. Feet)	Approx. Weight (lbs/ft)
Span (Ft.)	Rise (Ft.)	Top Slab	Bot. Slab	Wall		
3	2	7	6	4	5.8	830
3	3	7	6	4	8.6	930
4	2	7½	6	5	7.7	1120
4	3	7½	6	5	11.7	1240
4	4	7½	6	5	15.7	1370
5	3	8	7	6	14.5	1650
5	4	8	7	6	19.5	1800
5	5	8	7	6	24.5	1950
6	3	8	7	7	17.3	1970
6	4	8	7	7	23.3	2150
6	5	8	7	7	29.3	2320
6	6	8	7	7	35.3	2500
7	4	8	8	8	27.1	2600
7	5	8	8	8	34.1	2800
7	6	8	8	8	41.1	3000
7	7	8	8	8	48.1	3200
8	4	8	8	8	31.1	2800
8	5	8	8	8	39.1	3000
8	6	8	8	8	47.1	3200
8	7	8	8	8	55.1	3400
8	8	8	8	8	63.1	3600
9	5	9	9	9	43.9	3660
9	6	9	9	9	52.9	3880
9	7	9	9	9	61.9	4110
9	8	9	9	9	70.9	4330
9	9	9	9	9	79.9	4560
10	5	10	10	10	48.6	4380
10	6	10	10	10	58.6	4630
10	7	10	10	10	68.6	4880
10	8	10	10	10	78.6	5130
10	9	10	10	10	88.6	5380
10	10	10	10	10	98.6	5630
11	4	11	11	11	42.3	4880
11	6	11	11	11	64.3	5430
11	8	11	11	11	86.3	5980
11	10	11	11	11	108.3	6530
11	11	11	11	11	119.3	6810
12	4	12	12	12	46.0	5700
12	6	12	12	12	70.0	6300
12	8	12	12	12	94.5	6900
12	10	12	12	12	118.0	7500
12	12	12	12	12	142.0	8100

SOURCE : AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS

Handling Weight of Corrugated Steel Pipe (2⅔ × ½ in.)
Estimated Average Weights—Not for Specification Use*

Inside Diameter, in	Specified Thickness, in	Approximate Pounds per Lineal Ft**			
		Galvanized	Full-Coated	Full-Coated and Invert Paved	Full-Coated and Full Paved
12	0.052	8	10	13	
	0.064	10	12	15	
	0.079	12	14	17	
15	0.052	10	12	15	
	0.064	12	15	18	
	0.079	15	18	21	
18	0.052	12	14	17	
	0.064	15	19	22	
	0.079	18	22	25	
21	0.052	14	16	19	
	0.064	17	21	26	
	0.079	21	25	30	
24	0.052	15	17	20	
	0.064	19	24	30	45
	0.079	24	29	35	50
30	0.052	20	22	25	
	0.064	24	30	36	55
	0.079	30	36	42	60
36	0.052	24	26	29	
	0.064	29	36	44	65
	0.079	36	43	51	75
42	0.052	28	30	33	
	0.064	34	42	51	
	0.079	42	50	59	85
48	0.052	31	33	36	
	0.064	38	48	57	
	0.079	48	58	67	95
54	0.064	44	55	66	95
	0.079	54	65	76	105
60	0.079	60	71	85	
	0.109	81	92	106	140
66	0.109	89	101	117	160
	0.138	113	125	141	180
72	0.109	98	112	129	170
	0.138	123	137	154	210
78	0.109	105	121	138	200
	0.138	133	149	166	230
84	0.109	113	133	155	225
	0.138	144	161	179	240
90	0.109	121	145	167	
	0.138	154	172	192	
	0.168	186	204	224	
96	0.138	164	191	217	
	0.168	198	217	239	

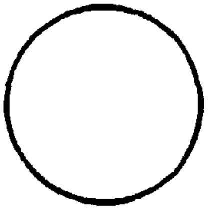
*Lock seam construction only; weights will vary with other fabrication practices.
**For other coatings or linings the weights may be interpolated.
****The handling weights for 1½ × ¼ in. and 2 × ½ in. are approximately the same as for 2⅔ × ½ in.*
Note: Pipe-Arch weights will be the same as the equivalent round pipe.
For example: for 42 × 29, 2⅔ × ½ in. Pipe-Arch, refer to 36 in. diameter pipe weight.
Smooth steel lined CSP weighs approximately 5% more than single wall galvanized.

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS

ROUND



Handling Weight of Corrugated Steel Pipe (3 × 1 in. or 5 × 1 in.)***
Estimated Average Weights—Not for Specification Use

Inside Diameter, in.	Specified Thickness, in.	Approximate Pounds per Lineal Ft**			
		Galvanized	Full-Coated	Full-Coated and Invert Paved	Full-Coated and Full Paved
54	0.064	50	66	84	138
	0.079	61	77	95	149
60	0.064	55	73	93	153
	0.079	67	86	105	165
66	0.064	60	80	102	168
	0.079	74	94	116	181
72	0.064	66	88	111	183
	0.079	81	102	126	197
78	0.064	71	95	121	198
	0.079	87	111	137	214
84	0.064	77	102	130	213
	0.079	94	119	147	230
90	0.064	82	109	140	228
	0.079	100	127	158	246
96	0.064	87	116	149	242
	0.079	107	136	169	262
102	0.064	93	124	158	258
	0.079	114	145	179	279
108	0.064	98	131	166	273
	0.079	120	153	188	295
114	0.064	104	139	176	289
	0.079	127	162	199	312
120	0.064	109	146	183	296
	0.079	134	171	210	329
	0.109	183	220	259	378
126	0.079	141	179	220	346
	0.109	195	233	274	400
132	0.079	148	188	231	363
	0.109	204	244	287	419
138	0.079	154	196	241	379
	0.109	213	255	300	438
144	0.109	223	267	314	458
	0.138	282	326	373	517

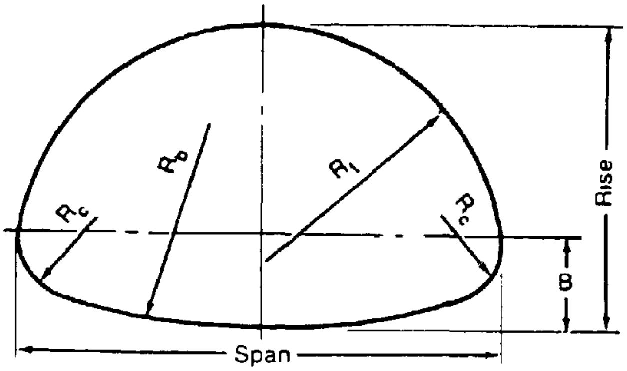
*Lock seam construction only; weights will vary with other fabrication practices.
**For other coatings or linings the weights may be interpolated.
***5 × 1 in. weighs approximately 12% less than 3 × 1 in.

Note: Pipe-Arch weights will be the same as the equivalent round pipe.
For example: for 81 × 59, 3 × 1 in. pipe arch, refer to 72-in. diameter pipe weight.
Smooth steel lined CSP weighs approximately 5% more than single wall galvanized.

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS



Sizes and Layout Details—CSP Pipe Arches
2⅔ × ½ in. Corrugation

Equiv. Diameter, in.	Span, in.	Rise, in.	Waterway Area, ft²	Layout Dimensions B in.	Rc in.	Rt in.	Rb in.
15	17	13	1.1	4⅛	3½	8⅝	25⅝
18	21	15	1.6	4⅞	4⅛	10¾	33⅛
21	24	18	2.2	5⅝	4⅞	11⅞	34⅝
24	28	20	2.9	6½	5½	14	42¼
30	35	24	4.5	8⅛	6⅛	17⅞	55⅛
36	42	29	6.5	9¾	8¼	21½	66⅛
42	49	33	8.9	11⅜	9⅝	25⅛	77¼
48	57	38	11.6	13	11	28⅝	88¼
54	64	43	14.7	14⅝	12⅜	32¼	99¼
60	71	47	18.1	16¼	13¾	35¾	110¼
66	77	52	21.9	17⅞	15⅛	39⅜	121¼
72	83	57	26.0	19½	16½	43	132¼

Dimensions shown not for specification purposes, subject to manufacturing tolerances.

Sizes and Layout Details—CSP Pipe-Arches
3 × 1 in. Corrugation

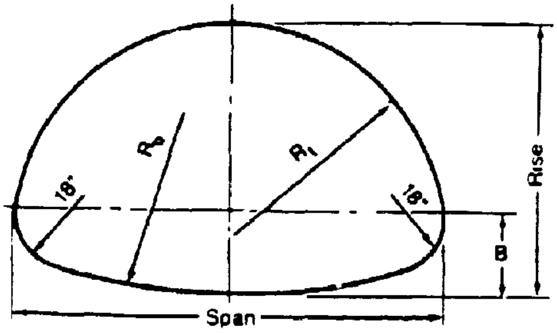
Equiv. Diameter, in.	Size, in.	Span, in.	Rise, in.	Waterway Area, ft²	Layout Dimensions B in.	Rc in.	Rt in.	Rb in.
54	60 × 46	58½	48½	15.6	20½	18¾	29⅜	51⅛
60	66 × 51	65	54	19.3	22¾	20¾	32⅝	56¼
66	73 × 55	72½	58¼	23.2	25⅛	22⅞	36¾	63¾
72	81 × 59	79	62½	27.4	23¾	20⅞	39½	82⅝
78	87 × 63	86½	67¼	32.1	25¾	22⅝	43⅜	92¼
84	95 × 67	93½	71¾	37.0	27¾	24⅜	47	100¼
90	103 × 71	101½	76	42.4	29¾	26⅛	51¼	111⅝
96	112 × 75	108½	80½	48.0	31⅜	27¾	54⅞	120¼
102	117 × 79	116½	84¾	54.2	33⅜	29½	59⅜	131¾
108	128 × 83	123½	89¼	60.5	35⅝	31¼	63¼	139¾
114	137 × 87	131	93¾	67.4	37⅜	33	67⅜	149½
120	142 × 91	138½	98	74.5	39½	34¾	71⅝	162⅜

Dimensions shown not for specification purposes, subject to manufacturing tolerances.

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS



Sizes and Layout Details—Structural Plate Steel Pipe-Arches
6 × 2 in. Corrugations—Bolted Seams
18-inch Corner Radius R_c

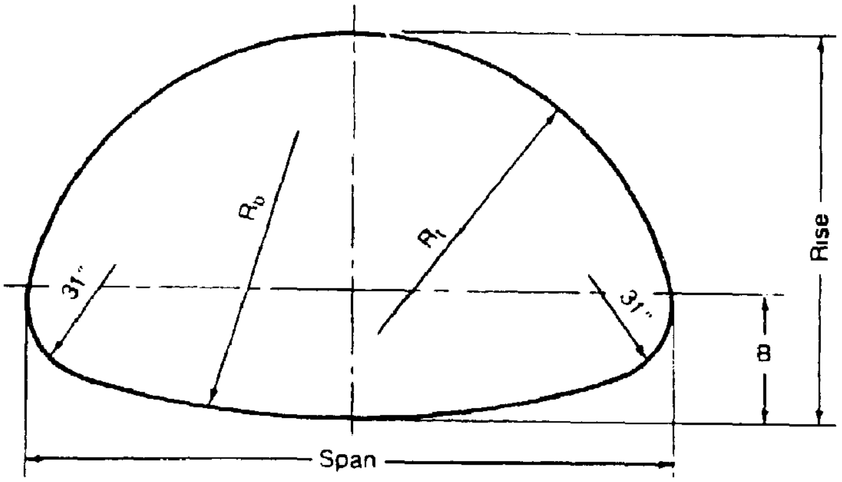
Dimensions		Waterway Area, ft²	Layout Dimensions			Periphery		
							Total	
Span, ft-in.	Rise, ft-in.		B in.	R_t ft	R_b ft	No. of Plates	N	Pi
6-1	4-7	22	21.0	3.07	6.36	5	22	66
6-4	4-9	24	20.5	3.18	8.22	5	23	69
6-9	4-11	26	22.0	3.42	6.96	5	24	72
7-0	5-1	28	21.4	3.53	8.68	5	25	75
7-3	5-3	31	20.8	3.63	11.35	6	26	78
7-8	5-5	33	22.4	3.88	9.15	6	27	81
7-11	5-7	35	21.7	3.98	11.49	6	28	84
8-2	5-9	38	20.9	4.08	15.24	6	29	87
8-7	5-11	40	22.7	4.33	11.75	7	30	90
8-10	6-1	43	21.8	4.42	14.89	7	31	93
9-4	6-3	46	23.8	4.68	12.05	7	32	96
9-6	6-5	49	22.9	4.78	14.79	7	33	99
9-9	6-7	52	21.9	4.86	18.98	7	34	102
10-3	6-9	55	23.9	5.13	14.86	7	35	105
10-8	6-11	58	26.1	5.41	12.77	7	36	108
10-11	7-1	61	25.1	5.49	15.03	7	37	111
11-5	7-3	64	27.4	5.78	13.16	7	38	114
11-7	7-5	67	26.3	5.85	15.27	8	39	117
11-10	7-7	71	25.2	5.93	18.03	8	40	120
12-4	7-9	74	27.5	6.23	15.54	8	41	123
12-6	7-11	78	26.4	6.29	18.07	8	42	126
12-8	8-1	81	25.2	6.37	21.45	8	43	129
12-10	8-4	85	24.0	6.44	26.23	8	44	132
13-5	8-5	89	26.3	6.73	21.23	9	45	135
13-11	8-7	93	28.9	7.03	18.39	9	46	138
14-1	8-9	97	27.6	7.09	21.18	9	47	141
14-3	8-11	101	26.3	7.16	24.80	9	48	144
14-10	9-1	105	28.9	7.47	21.19	9	49	147
15-4	9-3	109	31.6	7.78	18.90	9	50	150
15-6	9-5	113	30.2	7.83	21.31	10	51	153
15-8	9-7	118	28.8	7.89	24.29	10	52	156
15-10	9-10	122	27.4	7.96	28.18	10	53	159
16-5	9-11	126	30.1	8.27	24.24	10	54	162
16-7	10-1	131	28.7	8.33	27.73	10	55	165

Dimensions are to inside crests and are subject to manufacturing tolerances.
N = 3 Pi = 9.6 in.

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS



Sizes and Layout Details—Structural Plate Steel Pipe-Arches[1]

6 × 2 in. Corrugations—Bolted Seams

31-In Corner Radius, R_c

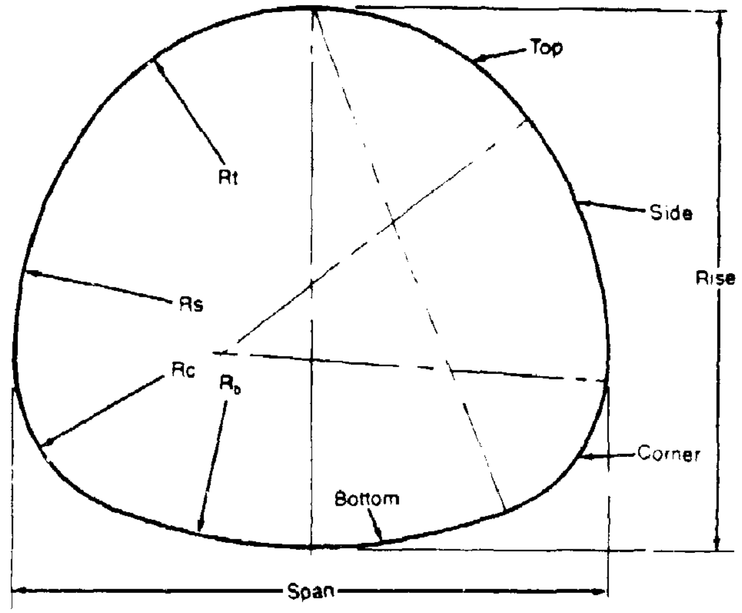
Dimensions		Waterway Area, ft²	Layout Dimensions			Periphery		
							Total	
Span, ft-in.	Rise, ft-in.		B in.	R_t ft	R_b ft	No. of Plates	*N*	Pi
13-3	9-4	97	38.5	6.68	16.05	8	46	138
13-6	9-6	102	37.7	6.78	18.33	8	47	141
14-0	9-8	105	39.6	7.03	16.49	8	48	144
14-2	9-10	109	38.8	7.13	18.55	8	49	147
14-5	10-0	114	37.9	7.22	21.38	8	50	150
14-11	10-2	118	39.8	7.48	18.98	9	51	153
15-4	10-4	123	41.8	7.76	17.38	9	52	156
15-7	10-6	127	40.9	7.84	19.34	10	53	159
15-10	10-8	132	40.0	7.93	21.72	10	54	162
16-3	10-10	137	42.1	8.21	19.67	10	55	165
16-6	11-0	142	41.1	8.29	21.93	10	56	168
17-0	11-2	146	43.3	8.58	20.08	10	57	171
17-2	11-4	151	42.3	8.65	22.23	10	58	174
17-5	11-6	157	41.3	8.73	24.83	10	59	177
17-11	11-8	161	43.5	9.02	22.55	10	60	180
18-1	11-10	167	42.4	9.09	24.98	10	61	183
18-7	12-0	172	44.7	9.38	22.88	10	62	186
18-9	12-2	177	43.6	9.46	25.19	10	63	189
19-3	12-4	182	45.9	9.75	23.22	10	64	192
19-6	12-6	188	44.8	9.83	25.43	11	65	195
19-8	12-8	194	43.7	9.90	28.04	11	66	198
19-11	12-10	200	42.5	9.98	31.19	11	67	201
20-5	13-0	205	44.9	10.27	28.18	11	68	204
20-7	13-2	211	43.7	10.33	31.13	12	69	207

[1] Dimensions are to inside crests and are subject to manufacturing tolerances.
N = 3 Pi = 9.6 in.

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS



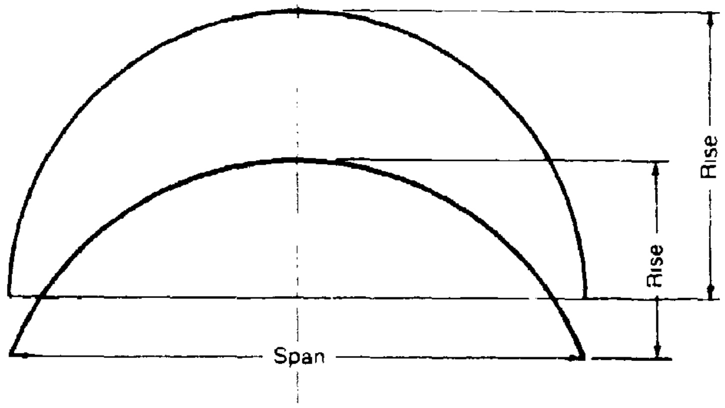
Structural Plate Steel Underpasses
Sizes and Layout Details

Span × Rise, ft and in.		Periphery			Layout Dimensions in In.			
		N	Pi	No. of Plates per Ring	R_t	R_s	R_c	R_b
5-8	5-9	24	72	6	27	53	18	Flat
5-8	6-6	26	78	6	29	75	18	Flat
5-9	7-4	28	84	6	28	95	18	Flat
5-10	7-8	29	87	7	30	112	18	Flat
5-10	8-2	30	90	6	28	116	18	Flat
12-2	11-0	47	141	8	68	93	38	136
12-11	11-2	49	147	9	74	92	38	148
13-2	11-10	51	153	11	73	102	38	161
13-10	12-2	53	159	11	77	106	38	168
14-1	12-10	55	165	11	77	115	38	183
14-6	13-5	57	171	11	78	131	38	174
14-10	14-0	59	177	11	79	136	38	193
15-6	14-4	61	183	12	83	139	38	201
15-8	15-0	63	189	12	82	151	38	212
16-4	15-5	65	195	12	86	156	38	217
16-5	16-0	67	201	12	88	159	38	271
16-9	16-3	68	204	12	89	168	38	246
17-3	17-0	70	210	12	90	174	47	214
18-4	16-11	72	216	12	99	157	47	248
19-1	17-2	74	222	13	105	156	47	262
19-6	17-7	76	228	13	107	158	47	295
20-4	17-9	78	234	13	114	155	47	316

All dimensions, to nearest whole number, are measured from inside crests.
Tolerances should be allowed for specification purposes. 6 × 2 in. Corrugations.

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Representative Sizes of Structural Plate Steel Arches

Dimensions(1)		Waterway Area, ft²	Rise over Span(2)	Radius, in.	Nominal Arc Length	
Span, ft	Rise, ft-in.				N(3)	Pi, in.
6.0	1-9½	7½	0.30	41	9	27
	2-3½	10	0.38	37½	10	30
	3-2	15	0.53	36	12	36
7.0	2-4	12	0.34	45	11	33
	2-10	15	0.40	43	12	36
	3-8	20	0.52	42	14	42
8.0	2-11	17	0.37	51	13	39
	3-4	20	0.42	48½	14	42
	4-2	26	0.52	48	16	48
9.0	2-11	18½	0.32	59	14	42
	3-10½	26½	0.43	55	16	48
	4-8½	33	0.52	54	18	54
10.0	3-5½	25	0.35	64	16	48
	4-5	34	0.44	60½	18	54
	5-3	41	0.52	60	20	60
11.0	3-6	27½	0.32	73	17	51
	4-5½	37	0.41	67½	19	57
	5-9	50	0.52	66	22	66
12.0	4-0½	35	0.34	77½	19	57
	5-0	45	0.42	73	21	63
	6-3	59	0.52	72	24	72
13.0	4-1	38	0.32	86½	20	60
	5-1	49	0.39	80½	22	66
	6-9	70	0.52	78	26	78
14.0	4-7½	47	0.33	91	22	66
	5-7	58	0.40	86	24	72
	7-3	80	0.52	84	28	84

(Table continued on following page)

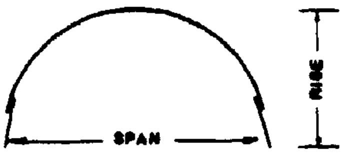
(1)Dimensions are to inside crests and are subject to manufacturing tolerances.
(2)R/S ratio varies from 0.30 to 0.52. Intermediate spans and rises are available.
(3W = 3 Pi = 9.6 in. 6 × 2 in. Corrugations—Bolted Seams.

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS

ARCH



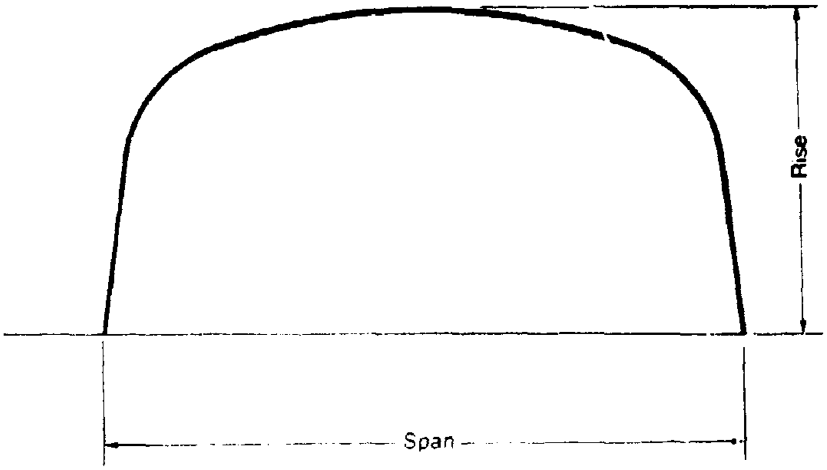
Continued. Representative Sizes of Structural Plate Steel Arches

Dimensions(1)		Waterway Area, ft²	Rise over Span(2)	Radius, in.	Nominal Arc Length	
Span, ft	Rise, ft-in.				N(3)	Pi, in.
15.0	4-7½	50	0.31	101	23	69
	5-8	62	0.38	93	25	75
	6-7	75	0.44	91	27	81
	7-9	92	0.52	90	30	90
16.0	5-2	60	0.32	105	25	75
	7-1	86	0.45	97	29	87
	8-3	105	0.52	96	32	96
17.0	5-2½	63	0.31	115	26	78
	7-2	92	0.42	103	30	90
	8-10	119	0.52	102	34	102
18.0	5-9	75	0.32	119	28	84
	7-8	104	0.43	109	32	96
	8-11	126	0.50	108	35	105
19.0	6-4	87	0.33	123	30	90
	8-2	118	0.43	115	34	102
	9-5½	140	0.50	114	37	111
20.0	6-4	91	0.32	133	31	93
	8-3½	124	0.42	122	35	105
	10-0	157	0.50	120	39	117
21.0	6-11	104	0.33	137	33	99
	8-10	140	0.42	128	37	111
	10-6	172	0.50	126	41	123
22.0	6-11	109	0.31	146	34	102
	8-11	146	0.40	135	38	114
	11-0	190	0.50	132	43	129
23.0	8-0	134	0.35	147	37	111
	9-10	171	0.43	140	41	123
	11-6	208	0.50	138	45	135
24.0	8-6	150	0.35	152	39	117
	10-4	188	0.43	146	43	129
	12-0	226	0.50	144	47	141
25.0	8-6½	155	0.34	160	40	120
	10-10½	207	0.43	152	45	135
	12-6	247	0.50	150	49	147

(1)Dimensions are to inside crests and are subject to manufacturing tolerances.
(2)R/S ratio varies from 0.30 to 0.52. Intermediate spans and rises are available.
(3)N = 3 Pi = 9.6 in. 6 × 2 in. Corrugations—Bolted Seams.

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Layout Details
Corrugated Steel Box Culverts

Rise, ft-in	Span, ft-in	Area ft^2	Rise, ft-in	Span, ft-in	Area ft^2
2-7	9-8	20.8	3-9	12-10	41.0
2-8	10-5	23.2	3-10	13-6	44.5
2-9	11-1	25.7	3-10	17-4	55.0
2-10	11-10	28.3	3-11	14-2	48.2
2-11	12-6	31.1	3-11	18-0	59.1
3-1	13-3	34.0	4-1	14-10	52.0
3-2	13-11	37.1	4-1	18-8	63.4
3-3	14-7	40.4	4-2	10-7	36.4
3-4	10-1	28.4	4-2	15-6	55.9
3-5	10-10	31.4	4-3	11-2	39.9
3-5	15-3	43.8	4-3	19-4	67.9
3-6	11-6	34.5	4-4	11-10	43.5
3-6	16-0	47.3	4-4	16-2	60.1
3-8	12-2	37.7	4-5	12-6	47.3
3-8	16-8	51.1	4-6	13-2	51.2

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS

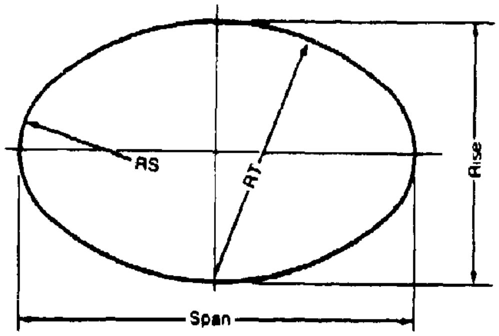
Continued.
Layout Details Corrugated Steel Box Culverts

Rise, ft-in.	Span, ft-in.	Area ft²	Rise, ft-in.	Span, ft-in.	Area ft²
4-6	16-10	64.4	6-9	13-7	77.9
4-7	17-6	68.9	6-9	16-9	99.3
4-7	20-8	77.6	6-10	14-2	83.3
4-8	13-10	55.3	6-10	17-4	105.1
4-9	14-6	59.5	7-0	14-9	88.9
4-9	18-1	73.5	7-0	17-11	111.1
4-10	15-1	63.8	7-0	20-8	127.2
4-11	11-0	44.7	7-1	15-4	94.6
4-11	18-9	78.4	7-2	18-6	117.3
5-0	11-7	48.7	7-3	12-3	71.5
5-0	15-9	68.3	7-3	15-10	100.5
5-1	12-3	52.9	7-4	12-10	77.1
5-1	16-4	73.0	7-4	16-5	106.5
5-1	19-5	83.4	7-4	19-1	123.6
5-2	12-10	57.2	7-5	13-5	82.8
5-3	17-0	77.8	7-6	13-11	88.6
5-4	13-6	61.7	7-6	17-0	112.7
5-5	14-1	66.2	7-8	14-6	94.5
5-5	17-7	82.8	7-8	17-6	119.0
5-5	20-8	94.1	7-9	15-0	100.6
5-6	14-9	71.0	7-9	18-1	125.5
5-7	18-3	88.0	7-11	15-7	106.8
5-8	11-5	53.3	7-11	18-7	132.1
5-8	15-4	75.8	8-0	12-8	81.1
5-8	18-10	93.4	8-0	16-1	113.1
5-9	12-0	57.9	8-1	19-2	138.9
5-9	16-0	80.9	8-2	16-8	119.6
5-10	12-7	62.6	8-2	13-9	93.3
5-10	19-6	98.9	8-3	19-8	145.9
5-11	16-7	86.1	8-4	17-2	126.2
6-0	13-3	67.4	8-5	14-10	106.0
6-1	13-10	72.4	8-5	17-8	133.0
6-1	17-2	91.4	8-7	18-3	139.9
6-2	14-5	77.5	8-7	20-9	160.3
6-2	17-9	96.9	8-8	15-10	119.2
6-2	20-8	110.6	8-9	18-9	147.0
6-4	15-0	82.7	8-11	16-10	132.9
6-4	18-4	102.6	8-11	19-3	154.2
6-5	11-10	62.2	9-1	19-9	161.6
6-5	15-7	88.1	9-3	17-10	147.1
6-6	18-11	108.5	9-5	20-9	176.9
6-7	12-5	67.3	9-6	18-10	162.0
6-7	16-2	93.6	9-10	19-10	177.4
6-8	13-0	72.5	10-2	20-9	193.5
6-8	19-6	114.5			

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS



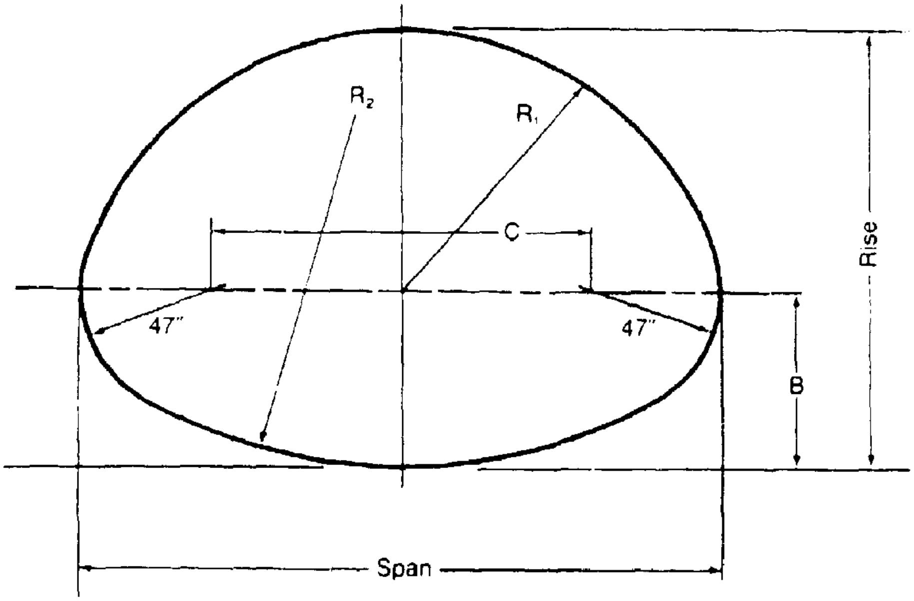
Long Span Horizontal Ellipse Sizes and Layout Details

Span, ft-in.	Rise, ft-in.	Area, ft²	Periphery						Inside Radius	
			Top or Bottom		Side		Total		Top Rad. in.	Side Rad. in.
			N	Pi	N	Pi	N	Pi		
19- 4	12- 9	191	22	66	10	30	64	192	12- 6	4- 6
20- 1	13- 0	202	23	69	10	30	66	198	13- 1	4- 6
20- 2	11-11	183	24	72	8	24	64	192	13- 8	3- 7
20-10	12- 2	194	25	75	8	24	66	198	14- 3	3- 7
21- 0	15- 2	248	23	69	13	39	72	216	13- 1	5-11
21-11	13- 1	221	26	78	9	27	70	210	14-10	4- 1
22- 6	15- 8	274	25	75	13	39	76	228	14- 3	5-11
23- 0	14- 1	249	27	81	10	30	74	222	15- 5	4- 6
23- 3	15-11	288	26	78	13	39	78	234	14-10	5-11
24- 4	16-11	320	27	81	14	42	82	246	15- 5	6- 4
24- 6	14- 8	274	29	87	10	30	78	234	16- 6	4- 6
25- 2	14-11	287	30	90	10	30	80	240	17- 1	4- 6
25- 5	16- 9	330	29	87	13	39	84	252	16- 6	5-11
26- 1	18- 2	369	29	87	15	45	88	264	16- 6	6-10
26- 3	15-10	320	31	93	11	33	84	252	17- 8	4-11
27- 0	16- 2	334	32	96	11	33	86	258	18- 3	4-11
27- 2	19- 1	405	30	90	16	48	92	276	17- 1	7- 3
27-11	19- 5	421	31	92	16	48	94	282	17- 8	7- 3
28- 1	17- 1	369	33	99	12	36	90	270	18-10	5- 5
28-10	17- 5	384	34	102	12	36	92	276	19- 5	5- 5
29- 5	19-11	455	33	99	16	48	98	294	18-10	7- 3
30- 1	20- 2	472	34	102	16	48	100	300	19- 5	7- 3
30- 3	17-11	415	36	108	12	36	96	288	20- 7	5- 5
31- 2	21- 2	512	35	105	17	51	104	312	20- 0	7- 9
31- 4	18-11	[illegible]	37	111	13	39	100	300	21- 1	5-11
32- 1	19- 2	471	38	114	13	39	102	306	21- 8	5-11
32- 3	22- 2	555	36	108	18	54	108	324	20- 7	8- 2
33- 0	22- 5	574	37	111	18	54	110	330	21- 1	8- 2
33- 2	20- 1	512	39	117	14	42	106	318	22- 3	6- 4
34- 1	23- 4	619	38	114	19	57	114	342	21- 8	8- 8
34- 7	20- 8	548	41	123	14	42	110	330	23- 5	6- 4
34-11	21- 4	574	41	123	15	45	112	336	23- 5	6-10
35- 1	24- 4	665	39	117	20	60	118	354	22- 3	9- 1
35- 9	25- 9	718	39	117	22	66	122	366	22- 3	10- 0
36- 0	22- 4	619	42	126	16	48	116	348	24- 0	7- 3
36-11	25- 7	735	41	123	21	63	124	372	23- 5	9- 7
37- 2	22- 2	631	44	132	15	45	118	354	25- 2	6-10
38- 0	26- 7	785	44	132	22	66	128	384	24- 0	10- 0
38- 8	27-11	843	42	126	24	72	132	396	24- 0	10-11
40- 0	29- 7	927	43	129	26	78	138	414	27-11	11-10

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS



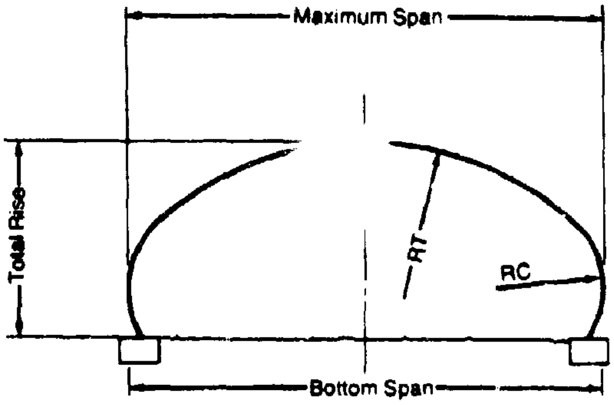
Long Span Pipe Arch Sizes and Layout Details

Span, ft-in.	Rise, ft-in.	Area, ft²	Total No. Plates	Periphery						B, in	C, in.	Inside Radius	
				Top		Bottom		Total				R₁, in	R₂, in
				N	Pi	N	Pi	N	Pi				
20- 0	13-11	218	10	34	102	20	60	68	204	62.8	146 2	172.5	223 6
20- 6	14- 3	231	10	36	108	20	60	70	210	61 4	152.3	124.7	255.7
21- 5	14- 6	243	11	36	108	22	66	72	216	65 3	162 8	131 4	236 7
21-11	14-11	256	11	38	114	22	66	74	222	63 7	168 9	133 5	268.1
22- 5	15- 3	270	11	40	120	22	66	76	228	62.1	174 6	135.5	307 1
23- 4	15- 7	284	11	40	120	24	72	78	234	66 2	185 5	142 4	280 2
24- 2	15-11	297	12	40	120	26	78	80	240	70 7	196 2	149 7	262 1
24- 8	16- 2	312	12	42	126	26	78	82	246	68 8	202.2	151.4	292.2
25- 2	16- 7	326	12	44	132	26	78	84	252	66 9	207 9	153 2	328 6
25- 7	16-11	342	12	46	138	26	78	86	258	64 8	213.3	155 0	373 3
26- 7	17- 3	357	12	46	138	28	84	88	264	69 4	224 7	162 1	339 4
27- 6	17- 6	372	12	46	138	30	90	90	270	74 2	235 8	169 6	315 8
28- 0	17-10	388	12	48	144	30	90	92	276	72.1	241.5	171 1	350 2
28- 5	18- 3	405	13	50	150	30	90	94	282	69.9	246 8	172 7	392 3
29- 4	18- 6	421	13	50	150	32	96	96	288	74 8	258 2	180.2	361.1
30- 4	18-10	438	14	52	156	34	102	100	300	80 0	269 4	188 2	339.1

*Includes 14N for two N7 corner plates.

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Long Span Low Profile Arch Sizes and Layout Details

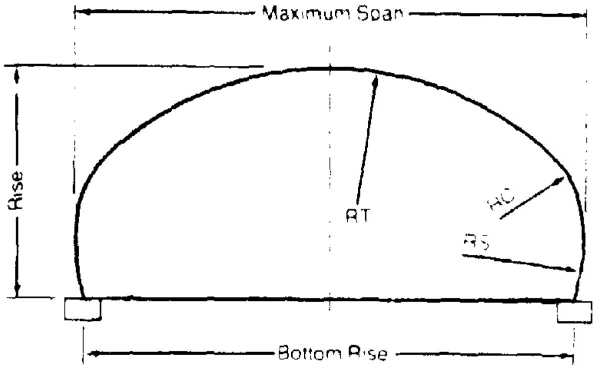
Max. Span, ft-in.	Bottom Span, ft-in.	Total Rise, ft-in.	Area, ft^2	Periphery						Inside Radius	
				Top		Side		Total		Top rad. in.	Side rad. in.
				N	Pi	N	Pi	N	Pi		
20- 1	19-10	7- 6	121	23	69	6	18	35	105	13- 1	4- 6
19- 5	19- 1	6-10	105	23	69	5	15	33	99	13- 1	3- 7
21- 6	21- 4	7- 9	134	25	75	6	18	37	111	14- 3	4- 6
22- 3	22- 1	7-11	140	26	78	6	18	38	114	14-10	4- 6
23- 0	22- 9	8- 0	147	27	81	6	18	39	117	15- 5	4- 6
23- 9	23- 6	8- 2	154	28	84	6	18	40	120	16- 0	4- 6
24- 6	24- 3	8- 4	161	29	87	6	18	41	123	16- 6	4- 6
25- 2	25- 0	8- 5	169	30	90	6	18	42	126	17- 1	4- 6
25-11	25- 9	8- 7	176	31	93	6	18	43	129	17- 8	4- 6
27- 3	27- 1	10- 0	217	31	93	8	24	47	141	17- 8	6- 4
28- 1	27-11	9- 7	212	33	99	7	21	47	141	18-10	5- 5
28- 9	28- 7	10- 3	234	33	99	8	24	49	147	18-10	6- 4
28-10	28- 8	9- 8	221	34	102	7	21	48	144	19- 5	5- 5
30- 3	30- 1	9-11	238	36	108	7	21	50	150	20- 7	5- 5
30-11	30- 9	10- 8	261	36	108	8	24	52	156	20- 7	6- 4
31- 7	31- 2	12- 1	309	36	108	10	30	56	168	20- 7	7- 3
31- 0	30-10	10- 1	246	37	111	7	21	51	153	21- 1	5- 5
32- 4	31-11	12- 3	320	37	111	10	30	57	171	21- 1	7- 3
31- 9	31- 7	10- 3	255	38	114	7	21	52	156	21- 8	5- 5
33- 1	32- 7	12- 5	330	38	114	10	30	58	174	21- 8	7- 3
33- 2	33- 0	11- 1	289	39	117	8	24	55	165	22- 3	6- 4
34- 5	34- 1	13- 3	377	39	117	11	33	61	183	22- 3.	8- 2
34- 7	34- 6	11- 4	308	41	123	8	24	57	183	23- 5	6- 4
37-11	37- 7	15- 8	477	41	123	14	42	69	207	23- 5	10-11
35- 4	35- 2	11- 5	318	42	126	8	24	58	174	24- 0	6- 4
38- 8	38- 4	15- 9	490	42	126	14	42	70	210	24- 0	10-11

NOTE. Larger sizes available for special designs.

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS



Long Span High Profile Arch Sizes and Layout Details

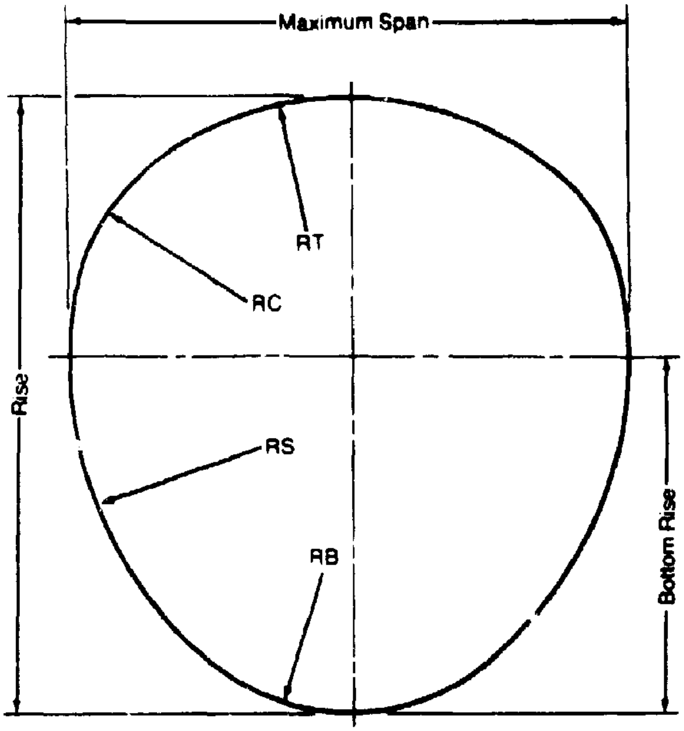
Max Span, ft-in.	Bottom Span, ft-in	Total Rise, ft-in	Area, ft²	Periphery								Inside Radius		
				Top		Upper Side		Lower Side		Total		Top Radius, ft-in	Upper Side, ft-in	Lower Side, ft-in
				N	Pi	N	Pi	N	Pi	N	Pi			
20- 1	19- 6	9- [illegible]	152	23	69	5	15	3	9	39	117	13- [illegible]	4- 6	13- [illegible]
20- 8	18-10	12- [illegible]	214	23	69	6	18	6	18	47	141	13- [illegible]	5- 5	13- [illegible]
21- 6	19-10	11- 6	215	25	75	5	15	6	18	47	141	14- 3	4- 6	14- 3
22-10	19-10	14- 7	285	25	75	7	21	8	24	55	165	14- 3	5- 4	14- 3
22- 3	20- 7	11-10	225	26	78	5	15	6	18	48	144	14-10	4- 6	14-10
22-11	20- 0	14- 0	276	26	78	6	18	8	24	54	162	14-10	5- 5	14-10
23- 0	21- 5	12- 0	235	27	81	5	15	6	18	49	147	15- 5	4- 6	15- 5
24- 4	21- 6	14-10	310	27	81	7	21	8	24	57	171	15- 5	[illegible]- 4	15- 5
23- 9	22- 2	12- 1	245	28	84	5	15	6	18	50	150	16- 0	4- 6	16- 0
24- 6	21-11	13- 9	289	29	87	5	15	8	24	55	165	16- 6	4- 6	16- 6
25- 9	23- 2	15- 2	335	29	87	7	21	8	24	59	177	16- 5	5- 4	16- 5
25- 2	23- 3	13- 2	283	30	90	5	15	7	21	54	162	17- 1	4- 6	17- 1
26- 6	24- 0	15- 3	348	30	90	7	21	8	24	60	180	17- 1	5- 4	17- 1
25-11	24- 1	13- 3	295	31	93	5	15	7	21	55	165	17- 8	4- 6	17- 8
27- 3	24-10	15- 5	360	31	93	7	21	8	24	61	183	17- 8	5- 4	17- 8
27- 5	25- 8	13- 7	317	33	99	5	15	7	21	57	171	18-10	4- 6	18-10
29- 5	27- 1	16- 5	412	33	99	8	28	8	24	65	195	18-10	7- 3	18-10
28- 2	25-11	14- 5	349	34	102	5	15	8	24	60	180	19- 5	4- 6	19- 5
30- 1	26- 9	18- 1	467	34	102	8	24	10	30	70	210	19- 5	7- 3	19- 5
30- 3	28- 2	15- 5	399	36	108	6	18	8	24	64	192	20- 7	5- 5	20- 7
31- 7	28- 4	18- 4	497	36	108	8	24	10	30	72	216	20- 7	7- 3	20- 7
31- 0	29- 0	15- 7	413	37	111	6	18	8	24	65	195	21- 1	5- 5	21- 1
31- 8	28- 6	17- 9	484	37	111	7	21	10	30	71	213	21- 1	5- 4	21- 1
32- 4	27-11	19-11	554	37	111	8	24	12	36	[illegible]	[illegible]	[illegible]	7- 3	21- 1
31- 9	28- 8	17- 3	470	38	114	6	18	10	30	[illegible]	[illegible]	[illegible]	5- 5	21- 8
33- 1	28- 9	20- 1	571	38	114	8	24	12	36	78	234	21- 8	7- 3	21- 8
32- 6	29- 6	17- 4	484	39	117	6	18	10	30	[illegible]	[illegible]	22- 3	5- 5	22- 3
33-10	29- 7	20- 3	588	39	117	8	24	12	36	79	237	22- 3	7- 3	22- 3
34- 0	31- 2	17- 8	514	41	123	6	18	10	30	73	219	23- 5	5- 5	23- 5
34- 7	30- 7	19-10	591	41	123	7	21	12	36	79	237	23- 5	6- 4	23- 5
35- 3	30- 7	21- 3	645	41	123	8	24	13	39	83	249	23- 5	7- 3	23- 5
37- 3	32- 6	23- 5	747	41	123	11	33	13	39	89	267	23- 5	10- 0	23- 5
34- 8	31-11	17-10	529	42	126	6	18	10	30	74	222	24- 0	5- 5	24- 0
35- 4	31- 5	20- 0	608	42	126	7	21	12	36	80	240	24- 0	6- 4	24- 0
36- 0	31- 5	21- 5	663	42	126	8	24	13	39	84	252	24- 0	7- 3	24- 0
38- 0	33- 5	23- 6	767	42	126	11	33	13	39	90	270	24- 0	10- 0	24- 0

NOTE Larger sizes available for special designs

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS



Long Span Pear Shape Sizes and Layout Details

Max Span, ft-in	Rise, ft-in	Rise Bottom, ft-in	Area	Periphery										Inside Radius			
				Top		Corner		Side		Bottom		Total		Bottom Radius, ft-in	Side Radius, ft-in	Corner Radius, ft-in.	Top Radius, ft-in.
				N	Pi	N	Pi	N	Pi	N	Pi	N	Pi				
23- 8	25- 8	14-11	481	25	75	5	15	24	72	15	30	98	294	8-11	16- 7	6- 3	14- 8
24- 0	25-10	15- 1	496	22	66	7	21	22	66	20	60	100	300	9-11	17- 4	7- 0	16- 2
25- 6	25-11	15-10	521	27	81	7	21	20	60	21	63	102	306	10- 7	18- 1	6-11	15-10
24-10	27- 8	16- 9	544	27	81	5	15	25	75	18	54	105	315	9- 3	19- 8	5- 9	15-11
27- 5	27- 0	18- 1	578	30	90	6	18	26	78	16	48	110	330	9- 7	20- 4	4- 7	19-11
26- 8	28- 3	18- 0	593	28	84	5	15	30	90	12	36	110	330	8- 0	20- 1	4- 9	20-11
28- 1	27-10	16-10	624	27	81	8	24	22	66	25	75	112	336	12- 2	19- 0	7- 3	20- 5
28- 7	30- 7	19- 7	689	32	96	7	21	24	72	24	72	118	354	11- 2	24- 0	7- 0	18- 2
30- 0	29- 8	20- 0	699	32	96	8	24	23	69	25	75	119	357	11-11	24- 0	6- 7	21-10
30- 0	31- 2	19-11	736	34	102	7	21	24	72	26	78	122	366	12- 1	24- 0	7- 0	19- 3

SOURCE : AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR ALUMINUM CULVERTS

Helical Pipe Availability, Weights and Fill Height Table HS-20 Loading

CORR. PATTERN				WEIGHT (Lbs./Lineal Ft.)						MINIMUM COVER (Ft.)		MAXIMUM COVER (Ft.)					
1-1 2 x 1 4	2 2 3 x 1 2	3 x 1	6 x 1	Equiv Standard Gauge						HS-20 Vehicle	Construction Vehicle	Equiv. Standard Gauge					
				18	16	14	12	10	8			18	16	14	12	10	8
Diameter (In.)																	
6				1.4	1.7					1.0		161	201				
8				1.8	2.2					1.0		119	149				
10				2.2	2.7					1.0		98	123				
	12				3.2	4.0	5.5			1.0	2.0		113	142	200		
	15				3.9	4.9	6.8			1.0	2.0		94	118	166		
	18				4.7	5.9	8.1			1.0	2.0		75	94	133		
	21				5.4	6.8	9.4			1.0	2.0		65	82	116		
	24				6.2	7.8	10.7	13.8		1.0	2.0		56	71	99	128	
	27				7.0	8.7	12.1	15.4		1.0	2.0		50	63	89	115	
	30				7.8	9.6	13.4	17.1		1.0	2.0		45	56	79	102	
		30			8.9	11.2	15.5	19.9		1.0	2.0		52	65	91	118	
	36					11.5	16.0	20.5		1.0	2.0			47	66	85	
		36			10.7	13.4	18.5	23.7		1.0	2.0		43	54	76	98	
	42						18.6	23.8		1.0	2.0				56	73	
		42			12.4	15.5	21.5	27.5		1.0	2.5		36	46	65	84	
	48						21.2	27.2	32.7	1.0	2.0				49	63	78
		48			14.1	17.7	24.5	31.4	37.8	1.0	2.5		32	40	57	73	90
			48		12.5	15.6	21.8	28.1	34.1	1.0	3.0		27	34	49	63	78
	54						23.8	30.5	36.7	1.0	2.0				43	56	69
		54			15.8	19.9	27.5	35.2	42.4	1.0	3.0		28	35	50	65	80
			54		14.0	17.5	24.5	31.5	38.3	1.0	3.0		24	30	43	56	69
	60							33.9	40.8	1.0	2.0					50	62
		60			17.6	22.0	30.5	39.0	47.0	1.0	3.0		25	32	45	58	72
			60		15.5	19.4	27.2	34.9	42.5	1.0	3.5		21	27	39	50	62
	66							37.2	44.8	1.0	2.0					46	56
		66			17.0	21.3	29.8	38.4	46.6	1.0	4.0		19	24	35	46	56
	72								48.8	1.0	2.0						51
		72				26.3	36.5	46.7	58.2	1.25	3.0			26	37	48	58
			72			23.2	32.5	41.8	50.8	1.25	3.5			22	32	42	51
	78								52.9	1.25	2.0						47
		78				28.5	39.5	50.5	60.8	1.25	3.0			24	34	44	56
			78			25.1	35.2	45.2	56.0	1.25	3.5			20	29	38	47
	84								56.9	1.25	2.5						44
		84				30.7	42.5	54.3	65.4	1.50	3.5			22	31	41	51
			84				37.8	48.7	58.1	1.50	3.0				27	35	44
		90					46.4	58.2	70.0	1.5	3.0				29	38	47
			90				40.5	52.1	63.3	1.5	3.0				25	33	41
		96					48.4	62.0	74.6	1.5	3.0				27	36	44
			96				43.2	55.5	67.5	1.5	3.5				23	31	38
		102					51.4	65.8	79.3	1.75	3.5				25	33	41
			102				46.8	58.9	71.6	1.75	3.5				22	29	36
		108					54.4	69.7	83.9	1.75	3.5				24	31	39
			108				48.5	62.4	75.8	1.75	3.5				20	27	33
		114					57.4	73.5	88.5	2.00	4.0				22	29	37
			114				51.2	66.8	80.0	2.00	4.0				19	25	31
		120					60.4	77.3	93.1	2.00	4.0				21	28	35
			120				53.8	69.2	84.1	2.00	3.5					24	30

NOTES. 1. Sizes 6" thru 10" are available in helical corrugation only.

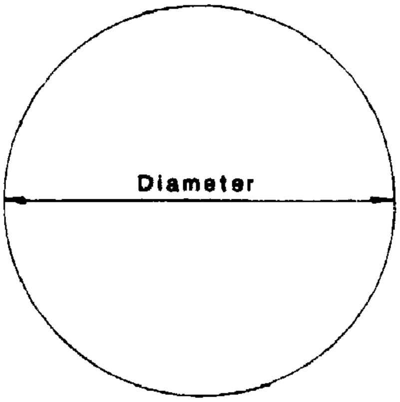
2. Sizes 12" through 21" in helical configuration have corrugation depth of 7/16" rather then 1/2".

3. Minimum cover for construction vehicle is based on a 44 cubic yard loaded scraper. For construction vehicle with greater or smaller axle load, this minimum cover should be adjusted per Figure 3-2 Formula 2 and 3, page 3-8.

4. Maximum covers for HS-20 vehicles are used for helical pipe. When annular corrugated pipe is used with riveted or bolted seams the maximum cover should be multiplied by the following coefficients.

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS



Geometric Data — Structural Plate Pipe

Nom. Diam. In.	Area Sq. Ft.	Total N	Nom. Diam. In.	Area Sq. Ft.	Total N
60	19	20	162	145	54
66	23	22	168	156	56
72	27	24	174	167	58
78	32	26	180	179	60
84	38	28	186	191	62
90	44	30	192	204	64
96	50	32	198	217	66
102	56	34	204	231	68
108	63	36	210	245	70
114	71	38	216	259	72
120	79	40	222	274	74
126	87	42	228	289	76
132	95	44	234	305	78
138	104	46	240	321	80
144	114	48	246	337	82
150	124	50	252	354	84
156	134	52	—	—	—

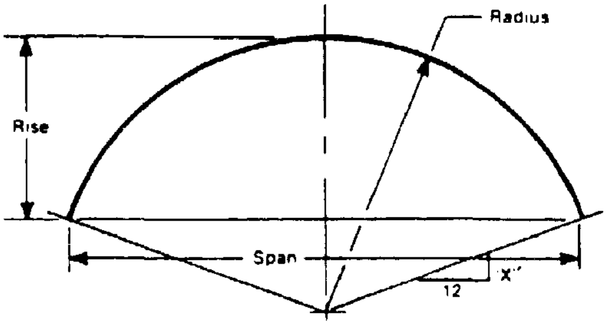
SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Arch

"X" Values For Rise Span Ratio

R/S Ratio	"X"	R/S Ratio	"X"
.30	6.40	.42	2.10
.31	5.96	.43	1.82
.32	5.54	.44	1.54
.33	5.13	.45	1.27
.34	4.74	.46	1.00
.35	4.37	.47	.74
.36	4.01	.48	.48
.37	3.67	.49	.24
.38	3.33	.50	.00
.39	3.01	.51	.24
.40	2.70	.52	.47
.41	2.40		



Typical Section

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/ Span Ratio	Radius Inches
5-0	2-7	10.4	10	.52	30
	2-3	8.5	9	.44	30¼
	1-9	6.5	8	.36	31¼
6-0	3-2	14.9	12	.52	36
	2-9	12.6	11	.46	36¼
	2-4	10.2	10	.38	37¼
	1-10	7.8	9	.30	40½
7-0	3-8	20.3	14	.52	42
	3-3	17.5	13	.46	42
	2-10	14.8	12	.40	43
	2-4	12.0	11	.34	45¼
8-0	4-2	26.4	16	.52	48
	3-9	23.3	15	.47	48
	3-4	20.2	14	.42	48¼
	2-11	17.0	13	.36	50½
	2-5	13.6	12	.30	54¼
9-0	4-8	33.4	18	.50	54
	4-3	29.9	17	.48	54
	3-10	26.3	16	.43	54½
	3-5	22.8	15	.38	56
	2-11	19.1	14	.33	59
10-0	5-2	41.2	20	.52	60
	4-10	37.3	19	.48	60
	4-5	33.3	18	.44	60½
	3-11	29.4	17	.40	61½
	3-6	25.3	16	.35	64
	3-0	21.1	15	.30	68½
11-0	5-8	49.8	22	.52	66
	5-4	45.5	21	.48	66
	4-11	41.2	20	.45	66½
	4-6	36.8	19	.41	67½
	4-0	32.4	18	.36	69¼
	3-6	27.8	17	.32	72¼

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data – Arch (Continued)

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/ Span Ratio	Radius Inches
12-0	6-3	59.3	24	52	72
	5-10	54.5	23	49	72
	5-5	49.8	22	45	72½
	5-0	45.0	21	42	73¼
	4-7	40.2	20	38	75
	4-1	35.3	19	34	77½
13-0	6-9	69.5	26	52	78
	6-4	64.4	25	49	78
	5-11	59.3	24	46	78¼
	5-6	54.1	23	42	79
	5-1	48.9	22	39	80½
	4-7	43.6	21	35	82¾
	4-1	38.1	20	31	86½
14-0	7-3	80.6	28	52	84
	6-10	75.1	27	49	84
	6-5	69.5	26	46	84¼
	6-0	64.0	25	43	85
	5-7	58.4	24	40	86
	5-2	52.7	23	37	88
	4-8	46.9	22	33	91¼
15-0	7-9	92.5	30	52	90
	7-5	86.5	29	49	90
	7-0	80.6	28	46	90¼
	6-7	74.7	27	44	91
	6-1	68.7	26	41	92
	5-8	62.6	25	38	93½
	5-2	56.4	24	34	96¼
	4-8	50.0	23	31	100½
16-0	8-3	105.2	32	52	96
	7-11	98.9	31	49	96
	7-6	92.5	30	47	96¼
	7-1	86.2	29	44	96¾
	6-8	79.8	28	41	97¾
	6-2	73.3	27	39	99¼
	5-9	66.8	26	36	101½
	5-3	60.0	25	32	105
17-0	8-10	118.7	34	52	102
	8-5	112.0	33	49	102
	8-0	105.2	32	47	102¼
	7-7	98.5	31	45	102¾
	7-2	91.7	30	42	103½
	6-9	84.9	29	39	105
	6-3	77.9	28	37	107
	5-9	70.9	27	34	110
	5-3	63.5	26	31	114¼
18-0	9-4	133.1	36	52	108
	8-11	125.9	35	50	108
	8-6	118.8	34	47	108¼
	8-1	111.6	33	45	108½
	7-8	104.5	32	43	109¼
	7-3	97.2	31	40	110½
	6-9	89.9	30	38	112½
	6-4	82.5	29	35	115
	5-9	74.8	28	32	116¾
19-0	9-10	148.2	38	52	114
	9-5	140.7	37	50	114
	9-0	133.2	36	48	114¼
	8-8	125.8	35	45	114½
	8-2	118.0	34	43	115¼
	7-9	110.4	33	41	116¼
	7-4	102.7	32	38	118
	6-10	94.9	31	36	120¼
	6-4	86.9	30	33	123½
	5-10	78.7	29	31	128¼
20-0	10-4	164.2	40	52	120
	10-0	156.3	39	50	120
	9-7	148.3	38	48	120
20-0 cont.	9-2	140.4	37	46	120½
	8-9	132.4	36	44	121
	8-3	124.4	35	41	122¼
	7-10	116.3	34	39	123½
	7-4	108.4	33	37	125¾
	6-10	99.8	32	34	128½
	6-4	91.2	31	32	132½
21-0	10-10	181.0	42	52	126
	10-6	172.7	41	50	126
	10-1	164.3	40	48	126
	9-8	156.0	39	46	126½
	9-3	147.6	38	44	127
	8-10	139.2	37	42	128
	8-4	130.7	36	40	129¼
	7-11	122.2	35	38	131¼
	7-5	113.5	34	35	133¾
	6-11	104.6	33	33	137¼
	6-4	95.4	32	30	142
22-0	11-5	198.6	44	52	132
	11-0	189.9	43	50	132
	10-7	181.1	42	48	132
	10-2	172.4	41	46	132½
	9-9	163.6	40	44	133
	9-4	154.8	39	42	133¾
	8-11	146.0	38	40	135
	8-5	137.0	37	38	135¾
	7-11	127.9	36	36	139
	7-5	118.7	35	34	142¼
	6-11	109.2	34	31	142¼
23-0	11-11	217.1	46	52	138
	11-6	207.9	45	50	138
	11-1	198.8	44	48	138
	10-8	189.6	43	47	138¼
	10-3	180.5	42	45	139
	9-10	171.3	41	43	139½
	9-5	162.0	40	41	140¾
	8-11	152.7	39	39	142¼
	8-6	143.2	38	37	144½
	8-0	133.8	37	35	147¼
	7-6	123.8	36	33	151
	6-11	113.8	35	30	156
24-0	12-5	236.3	48	52	144
	12-0	226.8	47	50	144
	11-7	217.2	46	48	144
	11-3	207.7	45	47	144¼
	10-10	198.1	44	45	144¾
	10-4	188.5	43	43	145½
	9-11	178.9	42	41	146½
	9-6	169.2	41	39	148
	9-0	159.3	40	38	150
	8-6	149.4	39	36	152½
	8-0	139.2	38	33	155¾
	7-6	128.9	37	31	160¼
25-0	12-11	256.4	50	52	150
	12-6	246.4	49	50	150
	12-2	236.5	48	49	150
	11-9	226.6	47	47	150¼
	11-4	216.8	46	45	150¾
	10-11	206.8	45	44	151½
	10-5	196.6	44	42	152½
	10-0	186.4	43	40	153¾
	9-6	176.3	42	38	154½
	9-1	165.9	41	36	157¾
	8-7	155.4	40	34	160¾
	8-1	144.7	39	32	164¾
	7-6	133.7	38	30	170
26-0	13-5	277.3	52	52	156
	13-1	266.9	51	50	156
	12-8	256.6	50	49	156

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

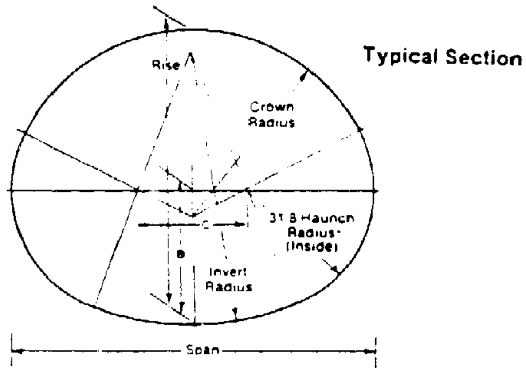
Geometric Data—Arch (Continued)

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/ Span Ratio	Radius Inches
26-0 cont	12-3	246.2	49	47	156¼
	11-10	235.9	43	46	156¾
	11-5	225.5	47	44	157¼
	11-0	215.1	46	42	158¼
	10-6	204.6	45	40	159½
	10-1	194.0	44	39	161
	9-7	183.3	43	37	163¼
	9-1	172.4	42	35	166
	8-7	161.4	41	33	169½
	8-1	150.1	40	31	174
27-0	14-0	299.0	54	52	162
	13-7	288.2	53	50	162
	13-2	277.5	52	49	162
	12-9	266.7	51	47	162¼
	12-4	256.0	50	46	162¾
	11-11	245.2	49	44	163¼
	11-6	234.4	48	43	164
	11-1	223.5	47	41	165¼
	10-7	212.6	46	39	166¾
	10-2	201.4	45	38	168¾
	9-8	190.2	44	36	171¼
	9-2	178.8	43	34	174½
	8-7	167.2	42	32	178½
	8-1	155.3	41	30	183¾
28-0	14-6	321.5	56	52	168
	14-1	310.4	55	50	168
	13-8	299.2	54	49	168
	13-3	288.1	53	47	168¼
	12-10	276.9	52	46	168½
	12-5	265.7	51	44	169¼
	12-0	254.5	50	43	170
	11-7	243.2	49	41	171
	11-1	231.9	48	40	172½
	10-8	220.4	47	38	174¼
28-0 cont	10-2	208.8	46	36	176½
	9-8	197.1	45	35	179½
	9-2	185.1	44	33	183¼
	8-8	172.9	43	31	188
29-0	15-0	344.8	58	52	174
	14-7	333.3	57	50	174
	14-2	321.7	56	49	174
	13-10	310.2	55	48	174¼
	13-5	298.6	54	46	174½
	13-0	287.1	53	45	175
	12-6	275.4	52	43	175¾
	12-1	263.8	51	42	176¾
	11-8	252.0	50	40	178¼
	11-2	240.2	49	39	180
	10-9	228.2	48	37	182
	10-3	216.1	47	35	184¾
	9-9	203.8	46	34	188
	9-2	191.3	45	32	192¼
	8-8	178.5	44	30	197¾
30-0	15-6	369.0	60	52	180
	15-1	357.1	59	50	180
	14-9	345.1	58	49	180
	14-4	333.2	57	48	180¼
	13-11	321.2	56	46	180½
	13-6	309.2	55	45	181
	13-1	297.2	54	44	181¾
	12-7	285.1	53	42	182¾
	12-2	273.0	52	41	184
	11-9	260.8	51	39	185½
	11-3	248.5	50	37	187½
	10-9	236.0	49	36	190
	10-3	223.3	48	34	193
	9-9	210.5	47	32	197
	9-2	197.3	46	31	201¾

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

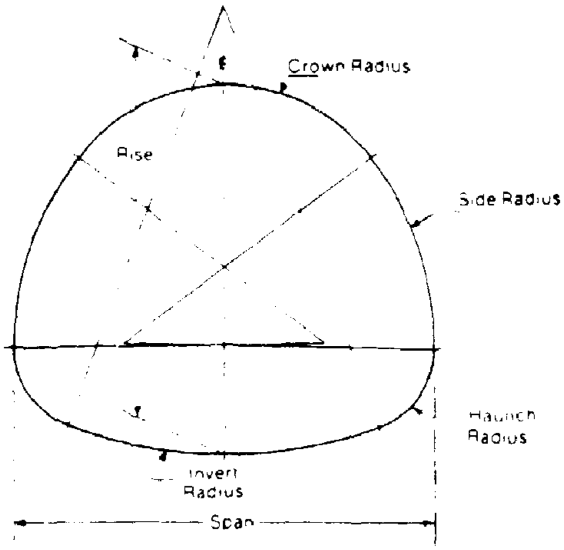
Geometric Data—Pipe Arch



Span Ft.-In	Rise Ft.-In	Area Sq. Ft.	Required N				Inside Radius		B	C
			Total	Crown	Invert	Haunch	Crown In.	Invert In.		
6-7	5-8	29 6	25	8	3	7	41 5	69 9	32 5	15 3
6-11	5-9	31 9	26	9	3	7	43 7	102 9	32 4	19 6
7-3	5-11	34 3	27	10	3	7	45 6	188 3	32 2	23 8
7-9	6-0	36 8	28	9	5	7	51 6	63 8	33 8	29 0
8-1	6-1	39 3	29	10	5	7	53 3	108 1	33 5	33 3
8-5	6-3	41 9	30	11	5	7	54 9	150 1	33 2	37 4
8-10	6-4	44 5	31	10	7	7	63 3	93 0	35 6	42 8
9-3	6-5	47 1	32	11	7	7	64 4	112 6	35 2	47 1
9-7	6-6	49 9	33	12	7	7	65 4	141 6	34 7	51 3
9-11	6-8	52 7	34	13	7	7	66 4	188 7	34 2	55 3
10-3	6-9	55 5	35	14	7	7	67 4	278 8	33 5	59 2
10-9	6-10	58 4	36	13	9	7	77 5	139 6	36 8	65 2
11-1	7-0	61 4	37	14	9	7	77 8	172 0	36 1	69 3
11-5	7-1	64 4	38	15	9	7	78 2	222 0	35 3	73 3
11-9	7-2	67 5	39	16	9	7	78 7	309 5	34 4	77 1
12-3	7-3	70 5	40	15	11	7	90 8	165 2	38 4	83 4
12-7	7-5	73 7	41	16	11	7	90 5	200 0	37 5	87 4
12-11	7-6	77 0	42	17	11	7	90 4	251 7	36 5	91 3
13-1	8-2	83 0	43	18	13	6	88 8	143 6	42 0	93 6
13-1	8-4	86 8	44	21	11	6	81 7	300 8	35 8	93 7
13-11	8-5	90 3	45	18	15	6	100 4	132 0	46 0	103 3
14-0	8-7	94 2	46	21	13	6	90 3	215 1	39 4	104 5
13-11	9-5	101 5	47	23	14	5	86 2	159 3	42 8	103 9
14-3	9-7	105 7	48	24	14	5	87 2	178 3	42 0	107 0
14-8	9-8	109 9	49	24	15	5	90 9	166 2	44 0	112 3
14-11	9-10	114 2	50	25	15	5	91 8	183 0	43 2	115 5
15-4	10-0	118 6	51	25	16	5	95 5	173 0	45 3	120 8
15-7	10-2	123 1	52	26	16	5	96 4	189 6	44 4	123 8
16-1	10-4	127 6	53	26	17	5	100 2	179 7	46 6	129 2
16-4	10-6	132 3	54	27	17	5	101 0	196 1	45 7	132 3
16-9	10-8	136 9	55	27	18	5	105 0	186 3	47 9	137 7
17-0	10-10	141 8	56	28	18	5	105 7	202 5	46 9	140 8
17-3	11-0	146 7	57	29	18	5	106 5	221 3	45 9	143 8
17-9	11-2	151 6	58	29	19	5	110 4	208 9	48 2	149 3
18-0	11-4	156 7	59	30	19	5	111 1	227 3	47 2	152 3
18-5	11-6	161 7	60	30	20	5	115 2	215 2	49 6	157 8
18-8	11-8	167 0	61	31	20	5	115 8	233 3	48 5	160 7
19-2	11-9	172 2	62	31	21	5	119 9	221 5	50 9	166 2
19-5	11-11	177 6	63	32	21	5	120 5	239 3	49 8	169 2
19-10	12-1	182 9	64	32	22	5	124 7	227 7	52 3	174 8
20-1	12-3	188 5	65	33	22	5	125 2	245 3	51 1	177 7
20-1	12-6	194 4	66	35	21	5	122 5	310 8	48 2	177 5
20-10	12-7	199 7	67	34	23	5	130 0	251 2	52 5	183 2
21-1	12-9	205 5	68	35	23	5	130 5	270 9	51 2	189 1
21-6	12-11	211 2	69	35	24	5	134 8	257 2	53 9	194 8

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS



Typical Section

Geometric Data—Vehicular Underpass

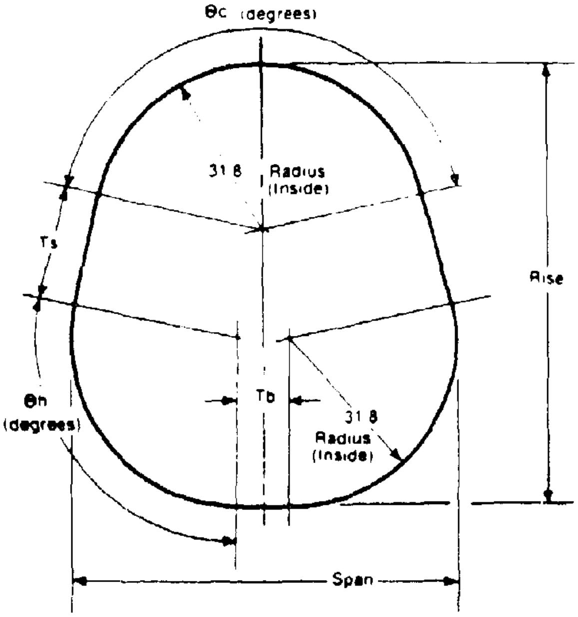
Span		Rise		Tot	Required N				Inside Radius (Inches)			
Ft	In.	Ft	In.	N	Invert	Haunch	Side	Crown	Invert	Haunch	Side	Crown
12	1	11	0	47	10.00	4.32	7.69	12.99	135.95	37.95	88.00	67.95
12	10	11	2	49	11.04	4.44	7.50	14.10	148.53	38.53	86.78	74.53
13	0	12	0	51	10.97	4.27	8.79	13.91	160.54	37.54	98.19	72.54
13	8	12	4	53	11.98	4.36	8.67	14.96	167.77	37.77	102.62	76.77
14	0	12	11	55	11.99	4.39	9.62	14.98	182.90	37.90	110.65	76.90
14	6	13	5	57	13.07	4.61	9.26	16.18	174.88	38.88	124.73	78.88
14	8	14	1	59	13.00	4.42	10.58	15.99	192.96	37.96	130.01	78.96
15	5	14	5	61	14.04	4.59	10.33	17.11	201.54	38.54	135.39	83.54
15	6	15	2	63	13.97	4.45	11.61	16.92	211.59	37.59	149.14	81.59
16	2	15	6	65	14.99	4.50	11.52	17.97	216.85	37.85	154.40	85.85
16	6	16	0	67	14.07	4.73	12.10	19.29	272.34	39.34	153.89	89.34
16	8	16	4	68	15.01	4.49	12.49	19.03	246.17	38.17	160.82	89.17
17	3	17	1	70	15.04	5.71	12.20	19.13	214.64	47.64	171.19	90.64
18	5	16	11	72	16.09	5.87	11.95	20.27	249.37	48.37	155.02	100.37
19	0	17	3	74	17.02	5.60	12.36	21.06	262.29	47.29	153.14	105.29
19	7	17	7	76	17.07	5.79	13.06	21.24	296.21	48.21	154.46	108.21
20	5	17	9	78	18.08	5.78	13.05	22.27	317.39	48.39	149.94	115.39

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Pedestrian/Animal Underpass

Span Ft.-In.	Rise Ft.-In.	Total N	Tb In.	Ts In.	θc Degrees	θh Degrees
6-1	5-9	24	9.2	7.2	100.2	129.9
6-3	6-1	25	11.1	11.0	119.3	120.4
6-3	6-6	26	11.6	15.6	136.5	111.7
6-2	7-0	27	10.2	21.1	152.2	103.9
6-3	7-4	28	11.6	25.2	153.3	103.4
6-1	7-10	29	9.8	30.9	161.7	99.2
6-3	8-2	30	11.3	35.0	161.3	99.3

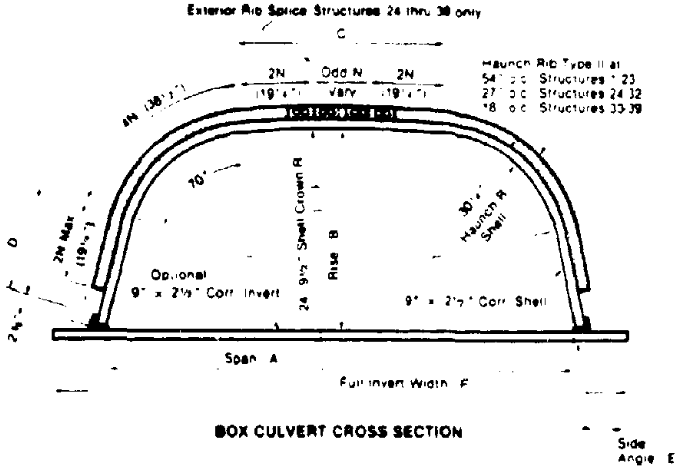


Typical Section

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Box Culvert Geometric Data and Fill Height Table—HS-20 Loading



BOX CULVERT CROSS SECTION

				SHELL							FULL INVERT				
												Supplemental/Stub PL			
Structure Number	Span "A" (Ft.-In.)	Rise "B" (Ft.-In.)	Area (Sq. Ft.)	Crown Width "C" (N)	Leg Length "D" (N)	Side Angle "E" Deg. Min.	Total N	Haunch Plate Length (N)	Crown Plate Length (N)	Bolts/Ft.	Width "F" (N)	Thick.	Width (N)	Weight/Ft	Bolts/Ft.
1	8- 9	2- 6	18.4	5	.5	15-24	14	1 @ 14	–	6.67	13	–	–	23.06	5.78
2	9- 2	3- 3	25.4	5	1.5	15-24	16	2 @ 8	–	11.56	13	–	–	23.06	5.78
3	9- 7	4- 1	32.8	5	2.5	15-24	18	2 @ 9	–	12.00	14	–	–	24.44	6.00
4	10- 0	4-10	40.2	5	3.5	15-24	20	2 @ 10	–	12.44	14	–	–	24.44	6.00
5	10- 6	5- 7	48.1	5	4.5	15-24	22	2 @ 11	–	12.89	15	–	–	25.82	6.22
6	10-11	6- 4	56.4	5	5.5	15-24	24	2 @ 12	–	13.33	17	–	–	28.58	6.57
7	11- 4	7- 2	65.0	5	6.5	15-24	26	2 @ 13	–	13.78	17	–	–	28.58	6.67
8	10- 2	2- 8	23.0	7	.5	13-31	16	2 @ 8	–	12.89	15	–	–	25.82	6.22
9	10- 7	3- 5	31.1	7	1.5	13-33	18	2 @ 9	–	13.33	15	–	–	25.82	6.22
10	10-11	4- 3	39.5	7	2.5	13-33	20	2 @ 10	–	13.78	17	–	–	28.58	6.67
11	11- 4	5- 0	48.2	7	3.5	13-33	22	2 @ 11	–	14.22	17	–	–	28.58	6.57
12	11- 8	5- 9	57.2	7	4.5	13-33	24	2 @ 12	–	14.67	17	–	–	28.58	6.57
13	12- 1	6- 7	66.4	7	5.5	13-33	26	2 @ 13	–	15.11	17	–	–	28.58	6.57
14	12- 5	7- 4	76.0	7	6.5	13-33	28	2 @ 14	–	15.56	17	–	–	28.58	6.57
15	11- 7	2-10	28.1	9	0.5	11-42	18	2 @ 9	–	14.67	17	–	–	28.58	6.57
16	11-11	3- 7	37.4	9	1.5	11-42	20	2 @ 10	–	15.11	17	–	–	28.58	6.57
17	12- 3	4- 5	46.9	9	2.5	11-42	22	2 @ 11	–	15.56	17	–	–	28.58	6.67
18	12- 7	5- 2	56.6	9	3.5	11-42	24	2 @ 12	–	16.00	19	–	–	32.02	7.11
19	12-11	6- 0	66.6	9	4.5	11-42	26	2 @ 13	–	16.44	19	–	–	32.02	7.11
20	13- 3	6- 9	76.8	9	5.5	11-42	28	2 @ 14	–	16.89	19	–	–	32.02	7.11
21	13- 0	3- 0	33.8	11	0.5	9-52	20	2 @ 10	–	16.44	19	–	–	32.02	7.11
22	13- 4	3-10	44.2	11	1.5	9-52	22	2 @ 11	–	16.89	19	–	–	32.02	7.11
23	13- 7	4- 7	54.8	11	2.5	9-52	24	2 @ 12	–	17.33	19	–	–	32.02	7.11
24	13-10	5- 5	66.6	11	3.5	9-52	26	2 @ 13	–	23.11	19	–	–	32.02	7.11
25	14- 1	6- 2	76.6	11	4.5	9-52	28	2 @ 14	–	23.56	20	–	–	33.34	12.14
26	14- 5	3- 3	40.0	13	0.5	8-1	22	2 @ 11	–	22.67	20	–	–	33.34	12.14
27	14- 6	4- 1	51.5	13	1.5	8-1	24	2 @ 8	8	25.56	21	100	2	40.23	12.57
28	14-10	4-10	63.2	13	2.5	8-1	26	2 @ 9	8	26.44	21	100	2	40.23	12.57
29	15- 1	5- 8	75.1	13	3.5	8-1	28	2 @ 10	8	26.89	21	100	2	40.23	12.57
30	15- 4	6- 5	87.2	13	4.5	8-1	30	2 @ 11	8	27.33	21	100	2	40.23	12.57
31	15- 6	7- 3	99.4	13	5.5	8-1	32	2 @ 12	8	27.78	22	100	2	41.61	12.99
32	15- 9	8- 0	111.8	13	6.5	8-1	34	2 @ 13	8	28.22	22	100	2	41.61	12.99
33	15-10	3- 8	46.8	15	0.5	6-10	24	2 @ 8	8	32.22	22	100	2	41.61	12.99
34	16- 0	4- 3	59.5	15	1.5	6-10	26	2 @ 9	8	33.56	22	100	2	41.61	12.99
35	16- 2	5- 1	72.3	15	2.5	6-10	28	2 @ 10	8	34.89	23	100	2	42.98	13.11
36	16- 4	5-11	86.2	15	3.5	6-10	30	2 @ 11	8	35.33	23	100	3	45.75	13.11
37	16- 6	6- 8	98.3	15	4.5	6-10	32	2 @ 12	9	35.78	23	100	3	45.75	13.11
38	16- 8	7- 6	111.5	15	5.5	6-10	34	2 @ 13	8	36.22	23	100	3	45.75	13.11
39	16-10	8- 3	124.8	15	6.5	6-10	36	2 @ 14	8	36.67	24	100	3	47.13	13.33

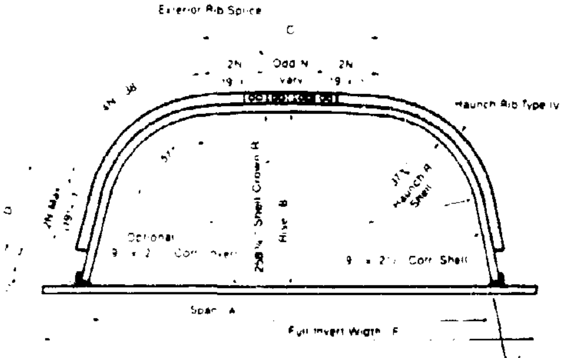
NOTES:

1) "N" equals 9.62"
2) All crowns of shells have Type IV ribs outside at 18" on centers
3) Weights per foot listed do not include bolt weight
4) Weight per foot of full invert includes 3½ x 3 x ¼ connecting angle and scalloped closure plate for each side. Inverts for 20N and greater are two-piece
5) Weight per foot of footing pad includes a 3½ x 3 x ¼ in. connecting angle for each side. Optional wale beam not included
6) Full invert plates are .100 thick. When reactions to invert require additional thickness supplemental plates of thickness and width listed are furnished to bolt between full invert and side connecting angle
7) Width of footing pad is for each side
8) For structures using short footing pads with leg length "D" equal to 3.5 N or more, either wale beam stiffeners should be used to avoid

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Box Culvert Geometric Data and Fill Height Table—HS-20 Loading



BOX CULVERT CROSS SECTION

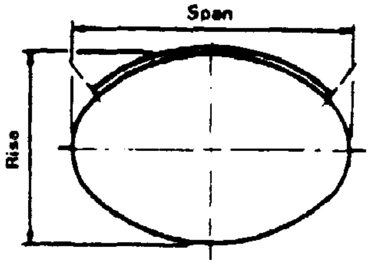
				SHELL							FULL INVERT				
Structure Number	Span A (Ft In)	Rise B (Ft In)	Area (Sq Ft)	Crown Width C (N)	Leg Length D (N)	Side Angle E Deg Min	Total N	Haunch Plate Length (N)	Crown Plate Length (N)	Bolts Per Foot	Width F (N)	Supplemental Stub Plates Thickness	Supplemental Stub Plates Width (N)	Weight Per Foot	Bolts Per Foot
40	17 9	3 10	54.4	17	.5	14 54	26	8	10	33.56	25	.100	3	48.51	13.56
41	18 2	4 7	68.3	17	1.5	14 54	28	9	10	34.89	25	.100	3	48.51	13.56
42	18 7	5 4	82.5	17	2.5	14 54	30	10	10	36.22	26	.100	3	49.88	13.78
43	19 0	6 1	97.1	17	3.5	14 54	32	11	10	36.67	27	.100	3	51.26	14.00
44	19 5	6 11	111.9	17	4.5	14 54	34	12	10	37.11	27	.100	3	51.26	14.00
45	19 10	7 8	127.1	17	5.5	14 54	36	13	10	37.56	28	.100	3	52.64	14.22
46	20 3	8 5	142.8	17	6.5	14 54	38	14	10	38.00	28	.100	3	52.64	14.22
47	19 1	4 2	63.3	19	.5	12 47	28	8	12	34.89	27	.100	3	51.26	14.00
48	19 5	4 11	78.3	19	1.5	12 47	30	9	12	36.22	27	.100	3	51.26	14.00
49	19 9	5 8	93.6	19	2.5	12 47	32	10	12	37.56	27	.100	3	51.26	14.00
50	20 1	6 6	109.2	19	3.5	12 47	34	11	12	38.00	28	.100	3	52.64	14.22
51	20 6	7 3	125.0	19	4.5	12 47	36	12	12	54.44	29	.125	3	56.09	14.44
52	20 10	8 1	141.2	19	5.5	12 47	38	13	12	54.89	29	.100	3	54.02	14.44
53	21 2	8 10	157.6	19	6.5	12 47	40	14	12	55.33	30	.150	3	59.54	14.67
54	20 4	4 6	73.1	21	.5	10 40	30	8	14	49.56	29	.150	3	58.14	14.44
55	20 7	5 3	89.2	21	1.5	10 40	32	9	14	52.22	29	.125	3	56.09	14.44
56	20 11	6 1	105.5	21	2.5	10 40	34	10	14	54.89	29	.100	3	54.02	14.44
57	21 3	6 10	122.1	21	3.5	10 40	36	11	14	55.33	30	.150	3	59.54	14.67
58	21 6	7 8	139.0	21	4.5	10 40	38	12	14	55.78	30	.125	3	57.67	14.67
59	21 10	8 5	156.0	21	5.5	10 40	40	13	14	56.22	31	.175	3	62.99	14.89
60	22 1	9 3	173.3	21	6.5	10 40	42	14	14	56.67	31	.150	3	60.92	14.89
61	21 7	4 11	83.8	23	.5	8 32	32	9	14	50.89	30	.125	3	57.47	14.67
62	21 10	5 8	101.0	23	1.5	8 32	34	10	14	53.56	31	.175	3	62.99	14.89
63	22 1	6 8	118.4	23	2.5	8 32	36	11	14	56.22	31	.150	3	60.92	14.89
64	22 3	7 3	135.9	23	3.5	8 32	38	12	14	56.67	31	.150	4	65.05	14.89
65	22 6	8 1	153.7	23	4.5	8 32	40	13	14	57.11	32	.200	4	71.95	15.11
66	22 9	8 10	171.8	23	5.5	8 32	42	14	14	57.56	32	.175	4	69.19	15.11
67	23 0	9 8	189.6	23	6.5	8 32	44	15	14	58.00	32	.150	4	66.43	15.11
68	22 9	5 4	95.5	25	.5	6 25	34	10	14	52.22	32	.175	4	69.19	15.11
69	23 0	6 1	113.7	25	1.5	6 25	36	11	14	54.89	32	.150	4	66.43	15.11
70	23 2	6 11	132.1	25	2.5	6 25	38	12	14	57.56	33	.225	4	76.09	15.33
71	23 4	7 8	150.6	25	3.5	6 25	40	13	14	58.00	33	.200	4	73.33	15.33
72	23 6	8 6	169.3	25	4.5	6 25	42	14	14	58.44	33	.200	4	73.33	15.33
73	23 8	9 3	188.1	25	5.5	6 25	44	15	14	58.89	33	.175	4	70.57	15.33
74	23 10	10 1	207.0	25	6.5	6 25	46	16	14	59.33	34	.250	4	80.22	15.56
75	24 0	5 9	108.2	27	.5	4 18	36	10	16	53.56	34	.225	4	77.46	15.56
76	24 1	6 8	127.5	27	1.5	4 18	38	11	16	56.22	34	.225	4	77.46	15.56
77	24 3	7 4	146.8	27	2.5	4 18	40	12	16	58.89	34	.200	4	74.71	15.56
78	24 4	8 2	166.2	27	3.5	4 18	42	13	16	59.33	34	.200	4	74.71	15.56
79	24 5	8 11	185.7	27	4.5	4 18	44	14	16	59.78	34	.200	4	74.71	15.56
80	24 7	9 9	206.3	27	5.5	4 18	46	15	16	60.22	35	.300	4	87.12	15.78
81	24 8	10 6	225.0	27	6.5	4 18	48	16	16	60.67	35	.250	4	81.60	15.78
82	25 2	6 2	122.0	29	.5	2 11	38	11	16	54.89	35	.200	4	76.09	15.78
83	25 2	7 0	142.2	29	1.5	2 11	40	12	16	57.56	35	.200	4	76.09	15.78
84	25 3	7 9	162.4	29	2.5	2 11	42	13	16	60.22	36	.300	4	88.50	16.00
85	25 4	8 7	182.6	29	3.5	2 11	44	14	16	60.67	36	.300	4	88.50	16.00
86	25 4	9 5	202.9	29	4.5	2 11	46	15	16	61.11	36	.300	4	88.50	16.00
87	25 5	10 2	223.3	29	5.5	2 11	48	16	16	61.56	36	.300	4	88.50	16.00

NOTES:

1) N = 9.62"
2) All shells have Type IV ribs outside only. Both haunch and crown ribs are 18" on centers for structures 40 through 50 and 9" on centers for structures 51 through 87.
3) Weights per foot listed do not include bolt weight.
4) Weight per foot of full invert includes 3½ x 3 x ¼ connecting angle and scalloped closure plate for each side. Inverts for 30 N width and greater are two piece.
5) Full invert plates are .100" thick. When reactions to invert require additional thickness, supplemental plates of thickness and width listed are furnished to bolt between full invert and side connecting angles. When thickness listed is greater than a .250" supplemental plates will be two pieces equalling the composite thickness required.
6) Weight per foot of footing pads includes 3½ x 3 x ¼ connecting angle for each side. Optional wale beam weight is not included.
7) Width of footing pads is for each side. When thickness listed is greater than .250" the footing pads will be two pieces equalling the composite thickness required.

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES FOR ALUMINUM CULVERTS

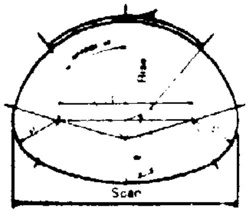


Span Ft-in	Rise Ft-in.	Area ft^2	Required N			Inside Radius	
			Crown or Invert	Haunch	Total	Crown & Invert in.	Haunch in
19 4	12 9	191	22	10	64	150 3	53 9
20 1	13 0	202	23	10	66	157 2	53 9
20 2	11 10	183	24	8	64	164 1	42 8
20 10	12 2	193	25	8	66	171 0	42 8
21 0	15 1	248	23	13	72	157 2	70 4
21 11	13 1	220	26	9	70	177 9	48 4
22 6	15 8	274	25	13	76	171 0	70 4
23 0	14 1	249	27	10	74	184 8	53 9
23 3	15 11	288	26	13	78	177 9	70 4
24 4	16 11	320	27	14	82	184 8	75 9
24 6	14 7	274	29	10	78	198 6	53 9
25 3	14 11	287	30	10	80	205 4	53 9
25 6	16 9	330	29	13	84	198 6	70 4
26 1	18 2	369	29	15	88	198 6	81 4
26 3	15 10	320	31	11	84	212.3	59 4
27 0	16 2	334	32	11	86	219 2	59 4
27 2	19 1	405	30	16	92	205 4	86 9
27 11	19 5	421	31	16	94	212 3	86 9
28 1	17 1	369	33	12	90	226 1	64 9
28 10	17 4	384	34	12	92	233 0	64 9
29 5	19 11	455	33	16	98	226 1	86 9
30 2	20 2	472	34	16	100	233 0	86 9
30 4	17 11	415	36	12	96	246 8	64 9
31 2	21 2	513	35	17	104	239 9	92 5
31 4	18 11	454	37	13	100	253 7	70 4
32 1	19 2	471	38	13	102	260 6	70 4
32 3	22 2	555	36	18	108	246 8	98 0
33 0	22 5	574	37	18	110	253 7	98 0
33 2	20 1	513	39	14	106	267 5	75 9
34 1	23 4	619	38	19	114	260 6	103 5
34 8	20 8	548	41	14	110	281 2	75 9
35 0	21 4	574	41	15	112	281 2	81 4
35 2	24 4	666	39	20	118	267 5	109 0
35 10	25 9	719	39	22	122	267 5	120 0
36 1	22 4	620	42	16	116	288 1	86 9
36 11	25 7	736	41	21	124	281 2	114 5
37 2	22 2	632	44	15	118	301 9	81 4
38 0	26 7	786	42	22	128	288 1	120 0
38 8	28 0	844	42	24	132	288 1	131 0
40 1	29 8	928	43	26	138	295 0	142 1

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Pipe Arch



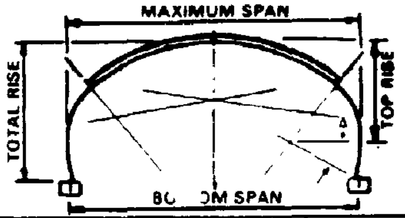
Span Ft-in	Rise Ft-in.	Area ft²	Required N				Inside Radius		B	C
			Total	Crown	Invert	Haunch	Crown in.	Invert in.		
20 1	13 11	216	68	34	20	7	122.7	224 2	62 9	146 7
20 7	14 3	229	70	36	20	7	124 9	256 4	61 4	152 8
21 5	14 7	241	72	36	22	7	131.7	237.3	65 4	163 4
21 11	14 11	254	74	38	22	7	133 7	268 8	63 8	169 4
22 8	15 3	267	76	39	23	7	138 2	274 9	65 0	177 8
23 4	15 7	281	78	40	24	7	142 7	281 0	66 3	186 1
24 3	15 10	295	80	40	26	7	150 0	262 8	70 8	196 8
24 9	16 3	309	82	42	26	7	151 7	293 0	68 9	202 9
25 5	16 7	324	84	43	27	7	156.2	299.0	70 2	211 3
26 4	16 10	339	86	43	29	7	163.9	281 3	75 0	222 1
27 0	17 2	354	88	44	30	7	168.6	287 4	76 4	230 5
27 9	17 6	369	90	45	31	7	173 3	293 5	77 9	238 9
28 5	17 10	385	92	46	32	7	178.0	299 6	79 3	247 3
29 4	18 2	401	94	46	34	7	186.6	286.7	84 6	257 9
29 10	18 6	418	96	48	34	7	187 5	311 6	82 3	264 2
30 4	18 10	435	98	50	34	7	188.6	340.1	80 0	270 2

See Notes Table 5-20A or 5-20B for rib spacing when required

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—High Profile Arch



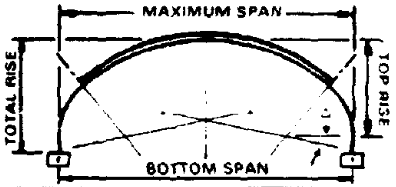
Max Span Ft.-in.	Total Rise Ft.-in.	Area ft²	Bottom Span Ft-in.	Top Rise Ft-in.	Required N				Inside Radius			Δ
					Crown	Haunch	Side	Total	Crown in.	Haunch in.	Side in.	Deg. Min.
20 1	9 1	152	19 6	6 6	23	5	3	39	157 2	54 0	157 2	11 40
20 9	12 1	214	18 10	7 3	23	6	6	47	157 2	65 0	157 2	22 8
21 8	11 8	215	19 10	6 9	25	5	6	47	171 0	54 0	171 0	20 20
22 10	14 6	284	19 10	8 6	25	7	8	55	171 0	76 0	171 0	26 48
22 3	11 9	224	20 7	6 11	26	5	6	48	177 9	54 0	177 9	19 33
22 11	14 0	275	20 1	7 7	26	6	8	54	177 9	65 0	177 9	25 44
23 0	11 11	234	21 5	7 1	27	5	6	49	184 8	54 0	184 8	18 49
24 4	14 10	309	21 7	8 5	27	7	8	57	184 8	76 0	184 8	24 50
23 9	12 1	244	22 2	7 2	28	5	6	50	191 7	54 0	191 7	18 8
24 6	13 8	288	21 11	7 4	29	5	8	55	198 6	54 0	198 6	23 2
25 10	15 1	334	23 3	8 9	29	7	8	59	198 6	76 0	198 6	23 6
25 3	13 1	283	23 3	7 5	30	5	7	54	205 4	54 0	205 4	19 35
26 6	15 3	347	24 0	8 10	30	7	8	60	205 4	76 0	205 4	22 19
26 0	13 3	294	24 1	7 7	31	5	7	55	212 3	54 0	212 3	18 57
27 3	15 5	360	24 10	9 0	31	7	8	61	212 3	76 0	212 3	21 36
27 5	13 6	317	25 8	7 10	33	5	7	57	226 1	54 0	226 1	17 48
28 5	18 5	412	27 1	10 0	33	8	8	65	226 1	87 0	226 1	20 18
28 2	14 5	348	25 11	8 0	34	5	8	60	233 0	54 0	233 0	19 37
30 2	18 0	464	28 8	10 2	34	8	10	70	233 0	88 0	233 0	23 51
30 4	15 5	399	28 2	9 0	36	6	8	64	246 8	65 0	246 8	18 34
31 7	18 4	497	28 5	10 4	36	8	10	72	246 8	87 0	246 8	23 3
31 1	15 7	412	29 0	9 1	37	6	8	65	253 7	65 0	253 7	18 3
31 8	17 9	483	28 7	9 10	37	7	10	71	253 7	76 0	253 7	22 25
32 4	19 11	554	27 11	10 8	37	8	12	77	253 7	87 0	253 7	26 45
31 9	17 2	468	28 9	9 3	38	6	10	70	260 6	65 0	260 6	21 47
33 1	20 1	571	28 9	10 8	38	8	12	78	260 6	87 0	260 6	26 3
32 8	17 4	484	29 6	9 4	39	6	10	71	267 5	65 0	267 5	21 14
33 10	20 3	588	29 7	10 9	39	8	12	79	267 5	87 0	267 5	25 23
34 0	17 8	514	31 2	9 8	41	6	10	73	281 2	65 0	281 2	20 11
34 8	19 10	581	30 7	10 4	41	7	12	79	281 2	76 0	281 2	24 7
35 4	21 3	645	30 7	11 0	41	8	13	83	281 2	87 0	281 2	26 8
37 3	23 4	747	32 7	13 2	41	11	13	89	281 2	120 0	281 2	26 8
34 9	17 9	529	31 11	9 9	42	6	10	74	288 1	65 0	288 1	19 42
35 5	20 0	608	31 5	10 8	42	7	12	80	288 1	76 0	288 1	23 33
36 1	21 5	663	31 5	11 2	42	8	13	84	288 1	87 0	288 1	25 28
38 0	23 6	767	33 5	13 3	42	11	13	90	288 1	120 0	288 1	25 31

See "Notes" Table 5-20A or 5-20B for rib spacing when required

SOURCE : ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Low Profile Arch

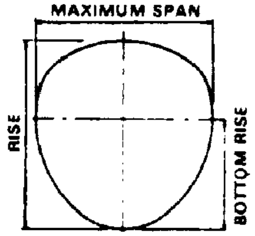


Max. Span Ft-in.		Total Rise Ft-in		Area ft²	Bottom Span Ft-in.		Top Rise Ft-in.		Required N			Inside Radius		Δ	
									Crown	Side	Total	Crown in.	Side in.	Deg.	Min.
20	1	7	6	120	19	10	6	8	23	6	35	157.2	54.0	12	19
19	5	6	9	105	19	2	5	10	23	5	33	157.2	43.0	15	22
21	6	7	9	133	21	4	6	9	25	6	37	171.0	54.0	12	19
22	3	7	11	140	22	1	6	11	26	6	38	177.9	54.0	12	19
23	0	8	0	147	22	10	7	1	27	6	39	184.8	54.0	12	19
23	9	8	2	154	23	6	7	2	28	6	40	191.7	54.0	12	19
24	6	8	3	161	24	3	7	4	29	6	41	198.6	54.0	12	19
25	3	8	5	168	25	0	7	5	30	6	42	205.4	54.0	12	19
26	0	8	7	175	25	9	7	7	31	6	43	212.3	54.0	12	19
27	3	10	0	217	27	1	9	0	31	8	47	212.3	76.0	8	51
28	1	9	6	212	27	11	8	7	33	7	47	226.1	65.0	10	17
28	9	10	3	234	28	7	9	3	33	8	48	226.1	76.0	8	52
28	10	9	8	220	28	8	8	8	34	7	48	233.0	65.0	10	17
30	4	9	11	237	30	2	9	0	36	7	50	246.8	65.0	10	17
31	0	10	8	261	30	10	9	8	36	8	52	246.8	76.0	8	52
31	7	12	1	309	31	2	10	4	36	10	56	246.8	87.0	14	0
31	1	10	1	246	30	10	9	1	37	7	51	253.7	65.0	10	17
32	4	12	3	319	31	11	10	6	37	10	57	253.7	87.0	14	0
31	9	10	2	255	31	7	9	3	38	7	52	260.6	65.0	10	17
33	1	12	5	330	32	8	10	8	38	10	58	260.6	87.0	14	0
33	2	11	0	289	33	0	10	1	39	8	55	267.5	76.0	8	52
34	6	13	3	367	34	1	11	6	39	11	61	267.5	98.0	12	28
34	8	11	4	308	34	6	10	4	41	8	57	281.2	76.0	8	52
37	11	15	7	478	37	8	13	10	41	14	69	281.2	131.0	9	23
35	5	11	5	318	35	3	10	8	42	8	58	288.1	76.0	8	52
38	8	15	9	491	38	4	14	0	42	14	70	288.1	131.0	9	23

See "Notes" Table 5-204 or 5-208 for rib spacing when required

SOURCE : ALUMINUM ASSOCIATION

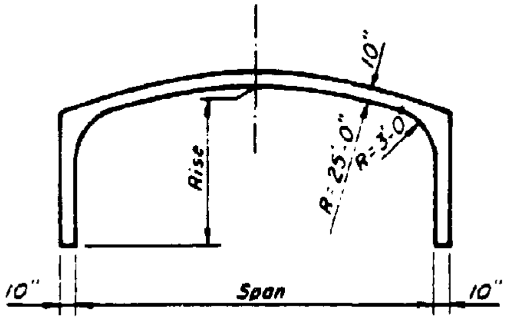
STANDARD SIZES
FOR ALUMINUM CULVERTS



Geometric Data—Pear Shape

Max. Span Ft.-in.	Rise Ft.-in.	Rise Bottom Ft-in.	Area ft²	Required N					Inside Radius			
				Top	Corner	Side	Bottom	Total	Bottom in.	Side in.	Corner in.	Top in
23 7	25 6	14 10	477	25	5	24	15	98	108 31	198 07	74 07	175 07
24 0	25 10	15 1	497	22	7	22	20	100	119 07	208 07	84 07	194 07
25 4	25 11	15 10	518	27	7	20	20	102	124 23	218 24	84 24	191 24
24 10	27 7	16 9	545	27	5	25	18	105	110 90	236 21	69 21	191 21
28 10	27 3	19 8	590	32	7	27	8	110	79 61	257 96	68 96	252 96
26 8	28 3	18 0	594	28	5	30	12	110	95 45	241 24	57 24	251 24
28 0	27 10	16 9	624	27	8	22	25	112	146 38	227 72	86 72	244 72
28 7	30 7	19 7	690	32	7	24	24	118	133 13	288 45	84 45	218 45
30 0	29 7	20 0	699	32	8	23	25	119	142 41	288 26	79 26	262 26
30 0	31 2	19 11	739	34	7	24	26	122	144 43	288 58	84 58	231 58

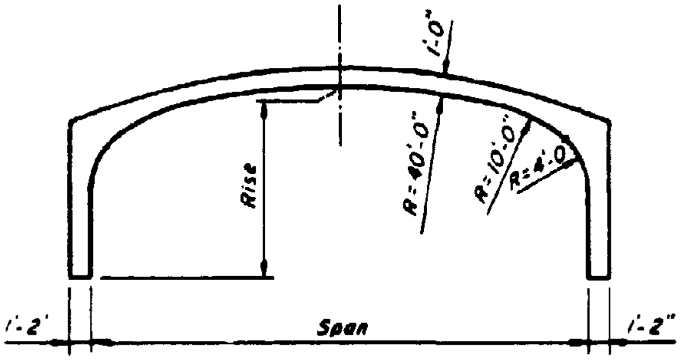
SOURCE : ALUMINUM ASSOCIATION



WATERWAY AREA (SQUARE FEET)			
RISE (FT.)	SPAN (FT.)		
	16	20	24
5	71	85	
6	87	105	119
7	103	125	143
8	119	145	167
9	135	165	191
10		185	215

SECTION
1/8" = 1'-0"

SHORT SPAN SERIES



WATERWAY AREA (SQUARE FEET)			
RISE (FT.)	SPAN (FT.)		
	28	32	36
8	195	216	
9	223	248	268
10	251	280	304
11	279	312	340
12		344	376
13			412

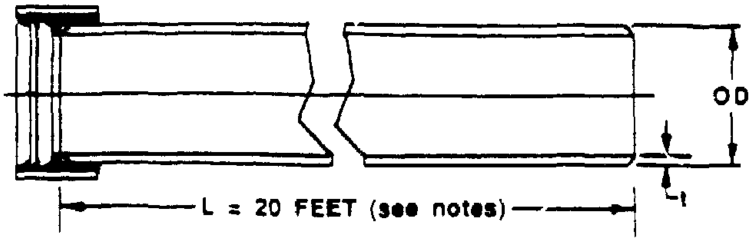
SECTION
1/8" = 1'-0"

LONG SPAN SERIES

GENERAL INFORMATION

Con/Span
Culvert Systems
1

STANDARD SIZES
FOR PLASTIC PIPE



Notes:
1. The standard length is 20 feet.
2. Tolerance on all lengths is ± 2 inches.

Table A — HOBAS gravity pipe

Nom. Dia. (in.)	OD (in.)	PS = 9 psi t (in.)	PS = 9 psi wt (lb./ft.)	PS = 18 psi t (in.)	PS = 18 psi wt. (lb./ft.)	PS = 36 psi t (in.)	PS = 36 psi wt. (lb./ft.)	PS = 72 psi t (in.)	PS = 72 psi wt. (lb./ft.)
18	19.5	0.23	10.6	0.30	14.1	0.37	17.6	0.45	22.0
20	21.6	0.26	13.0	0.33	17.2	0.40	21.6	0.50	27.0
24	25.8	0.30	18.6	0.38	24.4	0.47	30.7	0.59	38.3
30	32.0	0.35	25.8	0.47	37.5	0.58	47.2	0.72	58.7
36	38.3	0.43	41.2	0.55	53.6	0.69	67.4	0.85	83.7
42	44.5	0.50	55.7	0.64	72.1	0.80	91.0	0.99	112.6
48	50.8	0.57	72.4	0.72	93.0	0.90	118.4	1.12	146.3
54	57.1	0.64	91.5	0.81	118.5	1.01	149.6	1.25	184.4
60	62.9	0.70	111.0	0.89	143.7	1.11	181.5	1.38	223.3
66	69.2	0.77	134.5	0.97	173.8	1.22	219.6	1.51	269.8
72	75.4	0.83	174.4	1.06	206.3	1.33	260.8	1.64	319.7
78	81.6	0.90	187.3	1.14	241.3	1.43	305.3	1.77	373.8
84	88.0	0.97	217.6	1.23	280.8	1.54	354.7	1.90	434.3
90	94.3	1.04	250.2	1.31	322.0	1.65	407.4	2.04	498.1
96	100.6	1.10	284.6	1.40	366.8	1.76	463.6	2.17	566.4

Notes. Weight given does not include coupling; PS = pipe stiffness at 5% deflection.

Table C — Height of cover table

	Pressure Rating											
	Gravity		50 psi		100 psi		150 psi		200 psi		250 psi	
Pipe Stiffness (psi)	Max. Cover ft.	Min. Cover ft.	Max. Cover ft.	Min. Cover ft.	Max. Cover ft.	Min. Cover ft.	Max. Cover ft.	Min. Cover ft.	Max. Cover ft.	Min. Cover ft.	Max. Cover ft.	Min. Cover ft.
9	28	4										
18	28	2	25	4	28	4						
36	29	2	27	4	29	2	29	2	29	2		
72	30	2			30	2	30	2	30	2	30	2

Price Brothers HOBAS Pipe

Source: Price Brothers

STANDARD SIZES
FOR PLASTIC PIPE

Table D — Physical design values for HOBAS Pipe in nominal diameters from 18 inches to 96 inches

Gravity Pipe	**pipe stiffness 9, 18, 36, 72 psi**	
	Hoop flexural modulus	1.580 to 1.670 x 10^{6} psi
	Axial tensile modulus	0.390 to 0.630 x 10^{6} psi
	Density	110 to 121 pounds per cubic foot
Pressure Pipe	**pipe stiffness 18, 36, 72 psi**	
	pressure class 50, 100, 150, 200, 250 psi	
	Hoop flexural modulus	550 to 2.280 x 10
	Hoop tensile modulus	0.600 to 2.750 x 10
	Axial tensile modulus	0.370 to 1.640 x 10
	Hydrostatic design basis (HDB) Strain - 100.000 hours	0.0075 to 0.0098 inches per inch 0.75 to 0.98 percent
	Hydrostatic design basis (HDB) Strain - 50 years	0.0070 to 0.0091 inches per inch 0.70 to 0.91 percent
	Density	103 to 121 pounds per cubic foot
Gravity and Pressure Pipe	Thermal coefficient 16 x 10^{6} inches per inch per degree Fahrenheit	

Price Brothers HOBAS' Pipe

Source: Price Brothers

STANDARD SIZES
FOR PLASTIC PIPE

STRAIGHT PIPE DIMENSIONS

HIGH DENSITY POLYETHYLENE PIPING SYSTEMS WEHO HDPE

NOMINAL PIPE SIZE	Nominal Outside Diameter	DR 32.5			DR 26			DR 21			DR 17			DR 15.5		
		Nominal Inside Diameter	Minimum Wall Thickness	Nominal Weight (lb./ft.)	Nominal Inside Diameter	Minimum Wall Thickness	Nominal Weight (lb./ft.)	Nominal Inside Diameter	Minimum Wall Thickness	Nominal Weight (lb./ft.)	Nominal Inside Diameter	Minimum Wall Thickness	Nominal Weight (lb./ft.)	Nominal Inside Diameter	Minimum Wall Thickness	Nominal Weight (lb./ft.)
3	3.50				3.21	0.135	0.621	3.14	0.167	0.781	3.06	0.206	0.929	3.02	0.226	1.012
4	4.50				4.13	0.173	1.027	4.04	0.214	1.258	3.94	0.265	1.535	3.88	0.290	1.673
5	5.56			1.26	5.11	0.214	1.569	5.00	0.265	1.923	4.87	0.327	2.346	4.80	0.359	2.556
6	6.63	6.19	0.204	1.796	6.08	0.255	2.226	5.95	0.315	2.728	5.80	0.390	3.327	5.72	0.427	3.626
7	7.13	6.66	0.219	2.077	6.54	0.274	2.574	6.40	0.339	3.155	6.24	0.419	3.848	6.15	0.460	4.194
8	8.63	8.06	0.265	3.043	7.92	0.332	3.772	7.75	0.411	4.623	7.55	0.507	5.639	7.45	0.556	6.145
10	10.75	10.05	0.331	4.728	9.87	0.413	5.860	9.67	0.512	7.182	9.41	0.632	8.760	9.29	0.694	9.546
12	12.75	11.92	0.392	6.650	11.71	0.490	8.243	11.47	0.607	10.102	11.17	0.750	12.323	11.02	0.823	13.429
13	13.38	12.50	0.412	7.318	12.29	0.514	9.071	12.03	0.637	11.117	11.72	0.787	13.561	11.56	0.863	14.778
14	14.00	13.09	0.431	8.016	12.86	0.538	9.938	12.59	0.667	12.180	12.26	0.824	14.858	12.10	0.903	16.191
16	16.00	14.96	0.492	10.473	14.70	0.615	12.981	14.39	0.762	15.909	14.02	0.941	19.406	13.82	1.032	21.147
18	18.00	16.80	0.554	13.255	16.50	0.692	16.429	16.15	0.857	20.135	15.72	1.059	24.561	15.50	1.161	26.765
20	20.00	18.67	0.615	16.364	18.34	0.769	20.283	17.94	0.952	24.858	17.46	1.176	30.323	17.22	1.290	33.043
22	22.00	20.54	0.677	19.800	20.17	0.846	24.542	19.74	1.048	30.078	19.21	1.294	36.690	18.94	1.419	39.982
24	24.00	22.40	0.738	23.564	22.01	0.923	29.207	21.54	1.143	35.796	20.96	1.412	43.664	20.66	1.548	47.582
28	28.00	26.14	0.862	32.074	25.68	1.077	39.754	25.12	1.333	48.721	24.45	1.647	59.432	(24.11	1.806	64.764
32"	31.59	29.50	0.972	40.825	28.97	1.215	50.802	28.35	1.504	62.016	(27.59	1.858	75.649	(27.20	2.038	82.436
36	36.00	33.61	1.108	53.019	33.02	1.385	65.716	32.31	1.714	80.539	(31.44	2.118	98.245)			
40"	39.47	36.85	1.214	63.733	36.20	1.518	78.985	(35.42	1.879	98.813)						
42	42.00	39.21	1.292	72.165	38.52	1.615	89.446	(37.69	2.000	108.623)						
48"	47.38	44.24	1.458	91.838	43.46	1.822	113.829	(42.52	2.256	139.506)						
55"	55.30	51.63	1.701	125.107	50.71	2.127	155.085									
63"	63.21	59.02	1.945	163.486	(57.97	2.431	202.598)									

NOTE:
(1) 800 mm
(2) 1000 mm
(3) 1200 mm
(4) 1400 mm
(5) 1600 mm

Other diameters and DR's are available upon request.

WEHO HDPE pipe is manufactured in accordance with ASTM F714-81

WIIK & HOEGLUND

Source: Mid Continent Pipe and Supply Co.,Inc.

STANDARD SIZES
FOR PLASTIC PIPE

STRAIGHT PIPE DIMENSIONS

HiGH DENSITY POLYETHYLENE PIPING SYSTEMS WEHO HDPE

DR 13.5			DR 11			DR 9			DR 7.3			DR 6.3			
Nominal Inside Diameter	Minimum Wall Thickness	Nominal Weight (lb./ft.)	Nominal Inside Diameter	Minimum Wall Thickness	Nominal Weight (lb./ft.)	Nominal Inside Diameter	Minimum Wall Thickness	Nominal Weight (lb./ft.)	Nominal Inside Diameter	Minimum Wall Thickness	Nominal Weight (lb./ft.)	Nominal Inside Diameter	Minimum Wall Thickness	Nominal Weight (lb./ft.)	Nominal Pipe Size
2.95	0.259	1.149	2.82	0.318	1.383	2.68	0.389	1.650	2.48	0.479	1.971				3
3.79	0.333	1.900	3.63	0.409	2.286	3.44	0.500	2.728	3.20	0.616	3.259	2.99	0.714	3.674	4
4.69	0.412	2.903	4.49	0.506	3.494	4.26	0.618	4.169	3.96	0.762	4.980	3.70	0.883	5.615	5
5.59	0.491	4.118	5.35	0.602	4.956	5.07	0.736	5.913	4.71	0.908	7.064	4.41	1.052	7.964	6
6.01	0.528	4.763	5.76	0.648	5.732	5.46	0.792	6.839	5.07	0.976	8.170	4.74	1.131	9.212	7
7.28	0.639	6.979	6.97	0.784	8.399	6.60	0.958	10.022	5.14	1.182	11.972	5.74	1.369	13.498	8
9.07	0.796	10.841	8.69	0.977	13.048	8.23	1.194	15.569	7.65	1.473	18.598	7.16	1.706	20.959	10
10.76	0.944	15.251	10.31	1.159	18.354	9.77	1.417	21.901	9.07	1.747	26.162	(8.49	2.024	29.498)	12
11.29	0.991	16.782	10.81	1.216	20.198	10.25	1.486	24.101	(9.52	1.832	28.790)				13
11.81	1.037	18.388	11.32	1.273	22.130	10.72	1.556	26.406	(9.97	1.918	31.543)				14
13.50	1.185	24.016	12.94	1.455	28.904	12.26	1.778	34.490	(11.39	2.192	41.200)				16
15.12	1.333	30.396	14.47	1.636	36.581	13.69	2.000	43.651							18
16.81	1.481	37.526	16.08	1.818	45.162	(15.21	2.222	53.890)							20
18.49	1.630	45.406	(17.69	2.000	54.646)										22
20.17	1.778	54.037	(19.30	2.182	65.034)										24
(23.53	2.074	73.550)													28
(26.55	2.340	43.620)													32
															36
															40
															42
															48
															55
															63

Hydrostatic Design Basis	Standard Pressure Rating psig @ 73.4°F (23°C)									
	DR 32.5	DR 26	DR 21	DR 17	DR 15.5	DR 13.5	DR 11	DR 9	DR 7.3	DR 6.3
625 psi	40	50	63	78	86	100	125	156	198	236
725 psi	46	58	72	91	100	116	145	181	230	274
800 psi	50	64	80	100	110	128	160	200	254	300

WIIK & HOEGLUND

Source: Mid Continent Pipe and Supply Co.,Inc.

STANDARD SIZES
FOR PLASTIC PIPE

PLEXCO/SPIROLITE

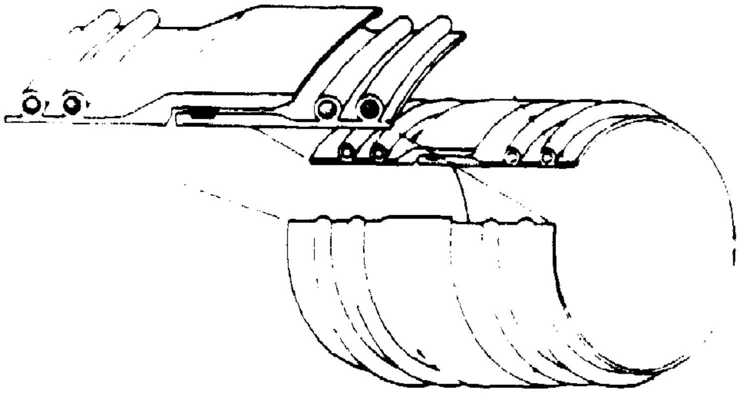
High Density Polyethylene Large Diameter Pipe

TABLE 1: PIPE DIMENSIONS AND TOLERANCES

		RSC CLASS 40	RSC CLASS 63	RSC CLASS 100	RSC CLASS 160
Nominal I.D. (Ins.)	Average I.D. (Ins.)	Min. Wall in Pipe Water-Way (Ins.)	Min. Wall in Pipe Water-Way (Ins.)	Min. Wall in Pipe Water-Way (Ins.)	Min. Wall in Pipe Water-Way (Ins.)
18	18.00 ± 0.20	0.19	0.19	0.19	0.24
21	21.00 ± 0.20	0.19	0.19	0.19	0.26
24	24.00 ± 0.20	0.19	0.19	0.24	0.27
27	27.00 ± 0.25	0.19	0.19	0.26	0.32
30	30.00 ± 0.25	0.19	0.24	0.26	0.28
33	33.00 ± 0.25	0.19	0.26	0.26	0.34
36	36.00 ± 0.25	0.19	0.26	0.30	0.36
42	42.00 ± 0.25	0.26	0.26	0.32	0.40
48	48.00 ± 0.25	0.26	0.28	0.36	0.43
54	54.00 ± 0.30	0.26	0.33	0.40	0.51
60	60.00 ± 0.30	0.28	0.32	0.40	0.55
66	66.00 ± 0.33	0.32	0.40	0.46	0.70
72	72.00 ± 0.36	0.32	0.40	0.49	0.93
78	78.00 ± 0.39	0.32	0.40	0.55	0.93
84	84.00 ± 0.42	0.40	0.45	0.70	0.98
90	90.00 ± 0.45	0.40	0.46	0.94	1.09
96	96.00 ± 0.48	0.40	0.56	0.93	1.19

TABLE 2: MINIMUM RING STIFFNESS CONSTANT (RSC) VALUES

Nominal Pipe Classification	RSC (LBS./FT. OF LENGTH)
40	36
63	56
100	90
160	144



CROSS SECTION OF A TYPICAL PROFILE

Chevron

Plexco/Spirolite™

Source: Plexco/Spirolite Corporation

STANDARD SIZES
FOR PLASTIC PIPE

SNAP-TITE® POLYETHYLENE LINER PIPE

*Required Snap-Tite® Liner Pipe

Corrugated Metal Pipe; — I.D.; inches	Snap-Tite Liner — O.D.; Nominal Sizes, Inches		
15	12		
18	14	16	
21	16	18	20
24	20	22	
30	24	28	
36	28	30	32
42	36	40	
48	40	42	
54	42	48	
60	48	55	
66	55		
72	55	63	
84	63		

*Provides Minimum 100% Flow based on Manning No. 0.009 for Liner and .024 for CMP

*Required Snap-Tite® Liner Pipe

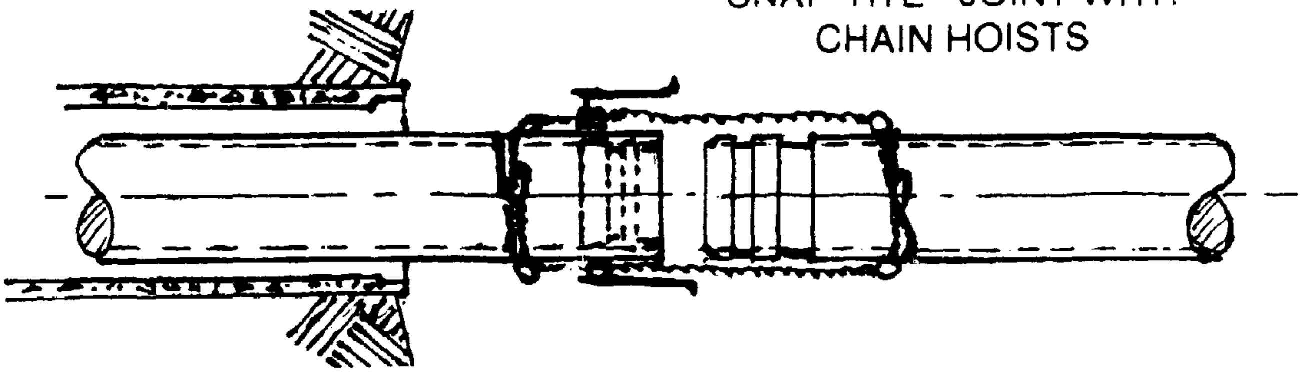
Existing Concrete Pipe I.D.; Inches	Snap-Tite® Liner — O.D.; Nominal Sizes, Inches			
Size	Size	% Flow	Size	% Flow
8	6	(84)		
10	8	(93)		
12	10	(106)		
15	13	(102)	12	(90)
18	16	(101)	14	(71)
21	20	(116)	18	(92)
24	22	(110)	20	(87)
27	24	(101)	22	(80)
30	28	(116)	24	(76)
36	32	(98)	28	(71)
42	40	(116)	36	(92)
48	42	(97)	40	(86)
54	48	(104)	42	(71)
60	55	(107)		
66	63	(103)		
72	63	(99)		

*Provides Indicated Percent (%) of Flow based on Manning No. 0.009 for Liner and .016 for Concrete Pipe

THE SNAP-TITE® SYSTEM

Source: Mid Continent
Pipe Co., Inc.

SNAP-TITE® JOINT WITH CHAIN HOISTS



1) Double-Wrap the chains. Tighten with chain binder. Approx. 2 ft. from coupling.

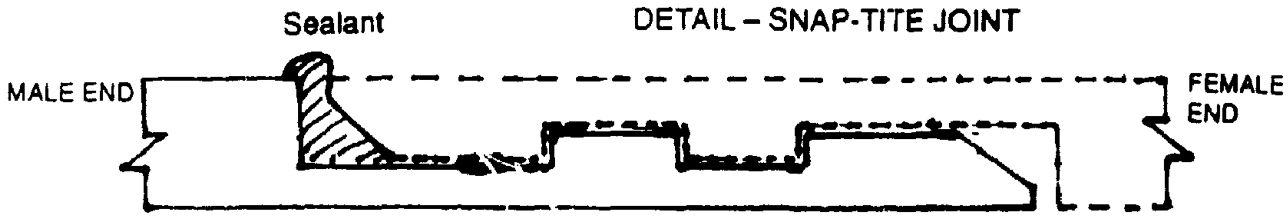
2) Use two (2) 2-ton chain hoists on opposite sides.

3) (a) Install Snap-Tite® Liner piece with female grooving into existing pipe. Leave approximately 3 feet exposed. Pieces must be in alignment.

(b) Keep grooves clean. This may require blocking up pipe slightly and/or laying a piece of plywood under the joint.

(c) The male end of the pipe should be aligned with the female. If pipe is out-of-round, roll until it matches. Assemble by pulling evenly with both chain hoists, keeping the pipe aligned.

DETAIL – SNAP-TITE JOINT



"O" Ring – If pressure tight joint is required, install sealant on last groove of male end or use "O" ring.

Other Procedures Include:
1) Special groove for Retainer Plate
2) Hydraulic Ram (Backhoe, etc.).
3) Combination of various procedures.
4) Chain Hoist on top and lift one end to start Joint.
5) Push/Pull Plate and cable through the existing culvert to snap Joint and pull Liner.

MID-CONTINENT PIPE, INC.
FAX (314) 326-3313 • (314) 349-1212
(800) 233-1306

STANDARD SIZES FOR PLASTIC PIPE

A-2000 PVC PIPE DETAILS

SECTION PROPERTIES

SIZE	INSIDE DIAMETER	OUTSIDE DIAMETER	AREA (in^2/foot)	C*	I ($in.^4$/in.)
4"	3.95"	4.29"	.658	.105"	.00021
6"	5.88"	6.41"	.842	.163"	.00070
8"	7.87"	8.59"	1.142	.222"	.00175
10"	9.84"	10.78"	1.176	.277"	.00334
12"	11.72"	12.80"	1.591	.330"	.00568
15"	14.34"	15.66"	1.884	.405"	.01040
18"	17.55"	19.15"	2.503	.493"	.01860

MECHANICAL PROPERTIES**
(CELL CLASS 12454B PVC RESIN)

INITIAL		50 YEAR	
MINIMUM TENSILE STRENGTH	MINIMUM MODULUS OF ELASTICITY	MINIMUM TENSILE STRENGTH	MINIMUM MODULUS OF ELASTICITY
7,000 PSI	400,000 PSI	3,700 PSI	140,000 PSI

*Extreme fiber distance from neutral axis. **Allowable long term strain = 5%

CONTECH
CONSTRUCTION PRODUCTS INC.

Source: Contech Construction
Products, Inc.

STANDARD SIZES
FOR PLASTIC PIPE

Driscopipe 1000

Dimensions and Pressure Ratings

NOMINAL SIZE INCHES	AVERAGE OD INCHES	MINIMUM WALL, INCHES						
		SDR 32.5 50 PSI	SDR 26 65 PSI	SDR 21 80 PSI	SDR 15.5 110 PSI	SDR 11 160 PSI	SDR 9 200 PSI	SDR 7 265 PSI
3	3.500	108	135	167	226	318	389	500
4	4.500	138	173	.214	.290	409	500	643
5	5.563	171	214	265	359	506	—	—
6	6.625	240	255	315	427	602	736	946
7	7.125	219	274	339	—	—	—	—
8	8.625	265	332	411	556	784	958	1.232
10	10.750	331	413	512	694	977	1.194	1.546
12	12.750	392	490	607	823	1.159	1.417	1.821
13	13.386	412	515	637	—	—	—	—
14	14.000	431	538	667	903	1.273	1.556	2.000
16	16.000	492	615	762	1.032	1.455	1.778	—
18	18.000	554	692	857	1.161	1.636	2.000	—
20	20.000	615	769	952	1.290	1.818	2.222	—
21.5	21.500	662	827	1.024	1.387	1.955	—	—
24	24.000	738	923	1.143	1.548	2.182	—	—
28	28.000	862	1.077	1.333	1.806	—	—	—
30	30.000	923	1.154	1.429	1.935	—	—	—
800mm	31.496	969	1.211	1.500	2.032	—	—	—
34	34.000	1.046	1.308	1.619	—	—	—	—
36	36.000	1.108	1.385	1.714	2.323	—	—	—
42	42.000	1.292	1.615	2.000	—	—	—	—
48	47.244	1.454	1.817	2.250	—	—	—	—

- Dimension and Pressure Ratings, where applicable, are in compliance with ASTM F714 Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter
- Short Term Surge Pressures to 2.5 times the pressure rating are allowed
- Inquire for availability of other sizes and pressure ratings

DRISCOPIPE

Phillips Driscopipe, Inc.
A Subsidiary of Phillips 66 Company

Source: Phillips Driscopipe, Inc.

STANDARD SIZES
FOR PLASTIC PIPE

SLIPLINING WITH Driscopipe 1000

1. ***INSPECT THE LINE***
   [illegible]

2. ***ECONOMICALLY SELECT EXCAVATIONS FOR INSERTION***
   From the TV [illegible] drawings [illegible] changes in line or grade

3. ***SPECIFY THE CORRECT O.D. OF THE LINER***
   Normally [illegible] condition [illegible] sliplining

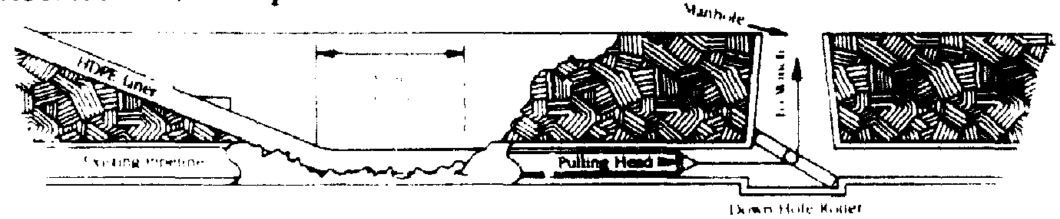
4. ***PREPARE THE LINER***
   Determine and measure lengths of pipe required. Butt fuse the [illegible] prescribed lengths and attach pulling head and tag line if required.

5. ***CLEAN THE LINE***
   Clear and clean the existing line sufficiently in order to insert the liner without undue stress.

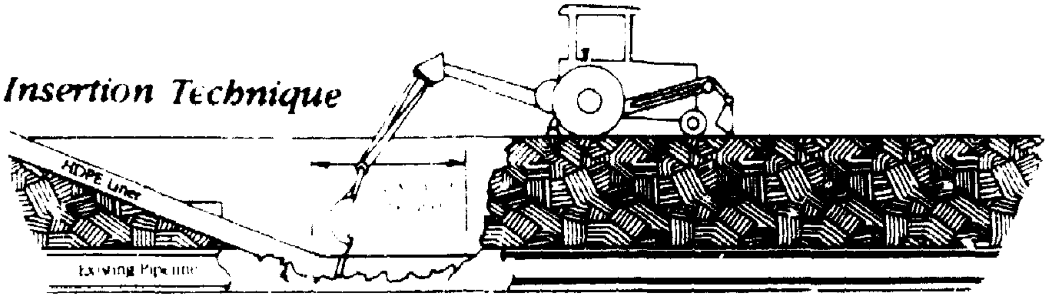
6. ***INSERT THE LINER***
   Establish pulling cable and rig. Attach cable to pulling head and slope excavation minimum of 2:1, then pull the liner into place. Alternately the liner may be pushed into place using a choker cable.

7. ***CLOSE THE JOB***
   Seal or grout around liner at manholes and cut inverts. Close excavations.

"Pull" Insertion Technique



"Push" Insertion Technique



Your Driscopipe representative can advise you on sizing your liner for external water head and other factors. Design brochures and reprints of ASTM F 585-78 "Insertion of Flexible Polyethylene Pipe into Existing Sewers" are available on request.

Source: Phillips Driscopipe, Inc.

APPENDIX B. REPAIR AND RETROFIT PROCEDURES

APPENDIX B-1. PROCEDURE FOR DEBRIS REMOVAL

APPLICATIONS

The following procedure is applicable to the removal of debris, both at the mouth of the culvert and inside the culvert barrel, that causes blockage of the waterway and impedes the flow of the stream.

COMMENTS

The need for removal of debris generally is based on reports from culvert inspections or as reported by culvert maintenance personnel. However, debris is likely to collect during a period of high water and should be removed prior to succeeding periods of high water to help reduce scour problems. Debris can also hold moisture against a structure, accelerating corrosion. Abrasion is accelerated by the continual movement of stones and other material that are not cleared from the culvert barrel.

PROCEDURES

The general procedure for removal of debris includes the following steps:

1. Place traffic control devices. Observe the work area and decide where to place the traffic control devices if they are required. Place advance warning signs and devices so that they can be seen by drivers in time to react. Keep tools off the roadway.

2. Assign the work. When cleaning culverts, position workers on both sides of the roadway to work as a team to minimize crossing the roadway.

3. Start by removing debris and obstructions in the channel around the mouth of the culvert and at the outlet end. Cut debris with a handsaw or chainsaw if necessary.

4. Clean inside the culvert barrel:

   a. If the culvert is large, send a crew inside to clean from each end, meeting in the middle.

   b. If the structure is a large box culvert, a small front-end loader can be used to remove the debris.

   c. If the culvert is too small to go inside, tie a rope to a long stick or pole. Push the stick and rope through the culvert to the other end. When the rope comes out the other end, tie it to a piece of wood or a metal bucket. Have the crew on the other end pull the rope and bucket through. This should clean out the debris.

5. It may be necessary to clean debris from a channel or natural water course beyond the right-of-way line to keep rains from washing material into a culvert inlet. Written permission should be obtained from the property owner before entering private property to clean up debris.

6. Load all the waste inside a wheel-barrow and properly dispose of it.

SAFETY PRECAUTIONS

Proper precautions should be taken to ensure the safety of workers. When air quality is questionable, tests for oxygen content and the presence of hazardous gases should be conducted prior to entry. Confined spaces should be mechanically ventilated continuously during occupancy. Scour holes and flash floods present drowning hazards. Steep embankments, toxic chemicals in streams, animals, poison ivy, and insects all present a danger.

RESOURCE COMMITMENT = 1:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. *Guide to Common Road and Equipment Maintenance Procedures*. Louisiana Transportation Research Center, Louisiana State University, Baton Rouge, Louisiana, 1989.

2. G. Richsen and L. J. Harrison, *Debris Control Structures,* Hydraulic Engineering Circular No. 9, Federal Highway Administration, Washington, DC, March 1971.

APPENDIX B-2. PROCEDURES FOR SEDIMENT REMOVAL

APPLICATIONS

The following procedure is applicable to the removal of sediment from the barrel of a culvert. Sediment can block the culvert, impeding the flow of the stream, or seriously reduce both the size of the opening and the ability of the culvert to handle peak flows.

COMMENTS

The need for removal of sediment generally is based on reports from culvert inspections or as reported by culvert maintenance personnel. In areas where construction activities have drastically altered or destroyed protective vegetative cover and soil mantle, the probability of the accumulation of sediment in culverts increases.

Sediment deposits at the inlet or within the culvert barrel reduce both the size of the opening and the capability of the culvert to handle peak flows. Culverts should be kept reasonably clear and unobstructed.

PROCEDURES

The general procedure for removal of sediment includes the following steps:

1. Observe the work area and decide where to place traffic control devices if they are required. Place advance warning signs and devices so that they can be seen by drivers in time to react. Keep tools off the roadway.

2. Assign the work. When cleaning culverts, position workers on both sides of the roadway to work as a team to minimize crossing the roadway.

3. If sediment is present throughout the length of the pipe, start cleaning at the outlet end.

4. Cleaning of sediment from drainage structures can be accomplished by a hand cleaning, mechanized cleaning, or a high pressure water stream:

    a. Hand tools, such as long-handled shovels or poles, can be used for cleaning out some installations.

    b. Mechanized cleaning is accomplished using a backhoe or grade-all to clean inlets and outlets on drainage structures. A small loader is utilized for cleaning inside larger drainage structures.

    c. The culvert can be flushed utilizing a high-pressure water stream, such as various types of hydro-jets. Local agencies have reported that this system has increased their production significantly. Occasionally, when this piece of equipment is not available to an agency, the fire department is requested to flush out a blockage in the culvert. It is possible that a local agency can rent such a unit or share equipment with another jurisdiction on a once- or twice-a-year basis when this work is done.

Adequate measures should be taken to protect the drainageway and prevent stream siltation or increased turbidity when culverts are hydraulically cleaned.

SAFETY PRECAUTIONS

Proper precautions should be taken to ensure the safety of workers. When air quality is questionable, tests for oxygen content and the presence of hazardous gases should be conducted prior to entry. Confined spaces should be mechanically ventilated continuously during occupancy. Scour holes and flash floods present drowning hazards. Steep embankments, toxic chemicals in streams, animals, poison ivy, and insects all present a danger.

RESOURCE COMMITMENT = 1:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

APPENDIX B-3. PROCEDURES FOR THAWING FROZEN CULVERTS

APPLICATIONS

The information provided below applies to short-term and long-term solutions and remedial action that may be taken to thaw all types of culverts that are frozen partially or completely closed.

COMMENTS

Roadway flooding and icing is a major problem in several northern States, especially during the spring thawing period. At this time of year, below- freezing soil temperatures surrounding roadway culverts can cause water to freeze inside the culvert. The subsequent damming and backing-up of the run-off waters can result in roadway flooding and icing.

PROCEDURES

A variety of methods are used to thaw frozen culverts. The following apparatus can be used:

1. Use of a truck or trailer-mounted boiler and a water-antifreeze solution. A thaw-pipe system is installed inside of the culvert. The boiler is connected to the thaw pipe, forming a closed-loop system. The hot water-antifreeze solution is heated and then circulated through the pipe system to thaw and unblock the frozen culvert. The amount of time required to thaw an opening in an ice-filled culvert is determined on the spot or from previous site history. For critical locations, it may be necessary to thaw daily. A conceptual view of the thaw culvert is shown in figure B.3.1.

   This method is labor-intensive and expensive.

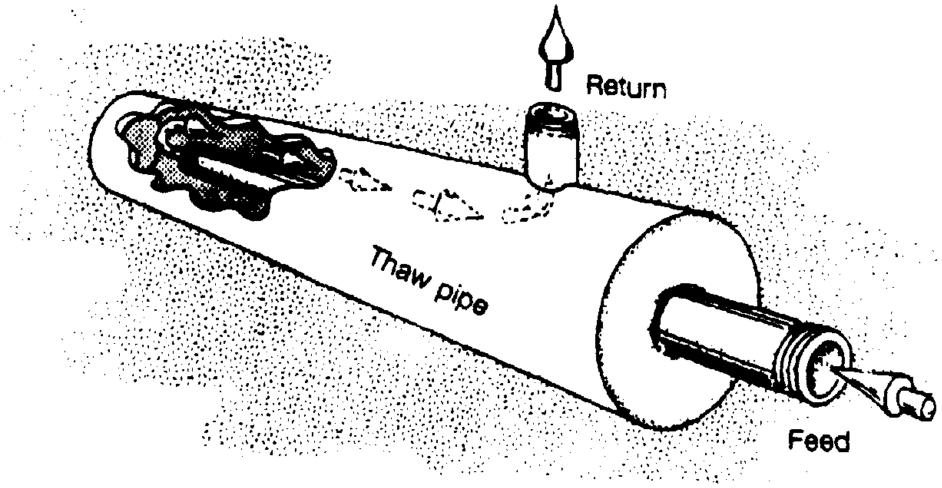


Figure B.3.1. Conceptual view of a thaw pipe.[2]

2. A steam generator and a steam probe that is forced through the ice in the culvert.

   This method is labor-intensive and expensive.

3. An oil-fired barrel stove, commonly called a "moose warmer," as shown in figure B.3.2. For use, one or more barrel stoves are set in the flow line upstream of the culvert. The barrel stove is made with a 55-gallon drum and simple burners that are ignited to burn fuel oil. The water passing around the barrel is warmed, which melts the ice to maintain a free flow through the culvert. A consumption of 50 gallons of fuel per culvert per day is typical for the "moose warmers" and, therefore, a daily delivery of oil is required at all locations using this system.

   This method is labor-intensive and expensive.

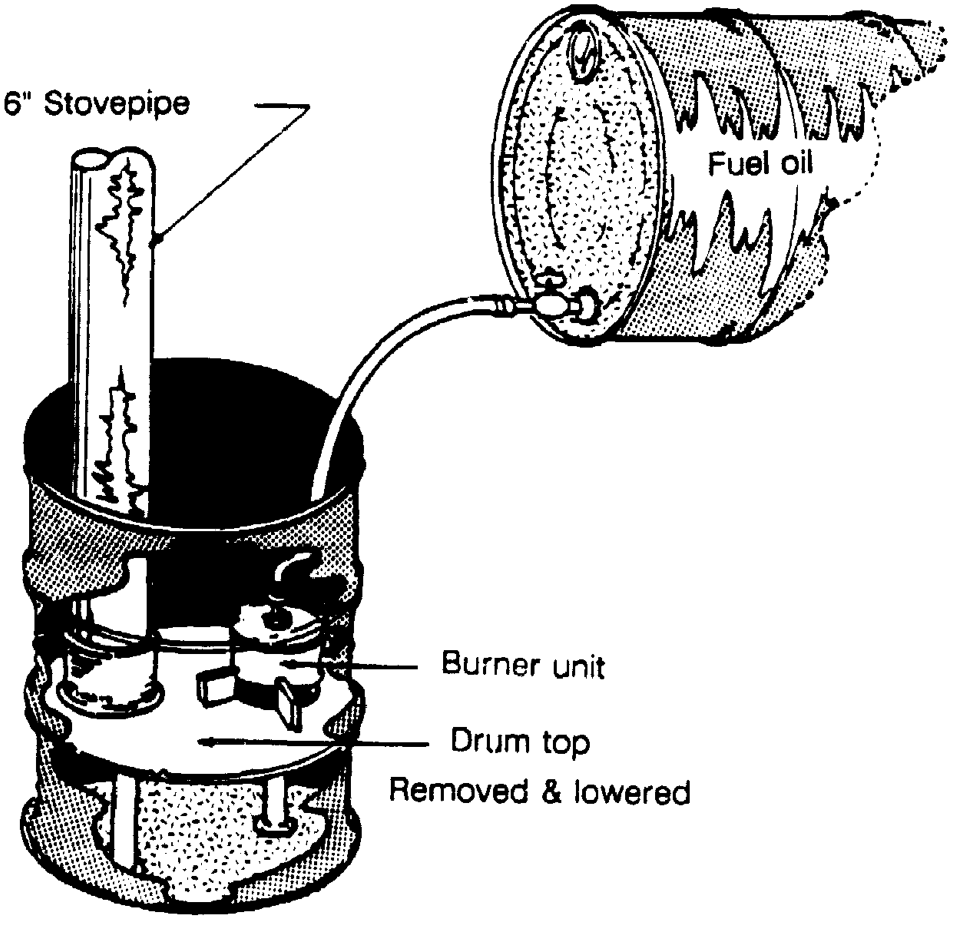


Figure B.3.2. Icing control burner.[2]

4. A solar energy collector system. A reflecting solar collector, as shown in figure B.3.3, consists of a metal tube or receiver of diameter D and a reflector of width W. Although a flat-plate type system may be used, a parabolic trough system may be more efficient and less susceptible to damage. The collector system may be installed in a fixed orientation position or it may be made to track the sun. Due to the lack of maintenance at remote sites where solar-assisted culvert- thawing devices would be used, the short season during which the system is required, and budget constraints, it may be more cost effective to install the collector in a fixed position. East-west, north-south, or some other orientation of the long axis of the collector is possible.

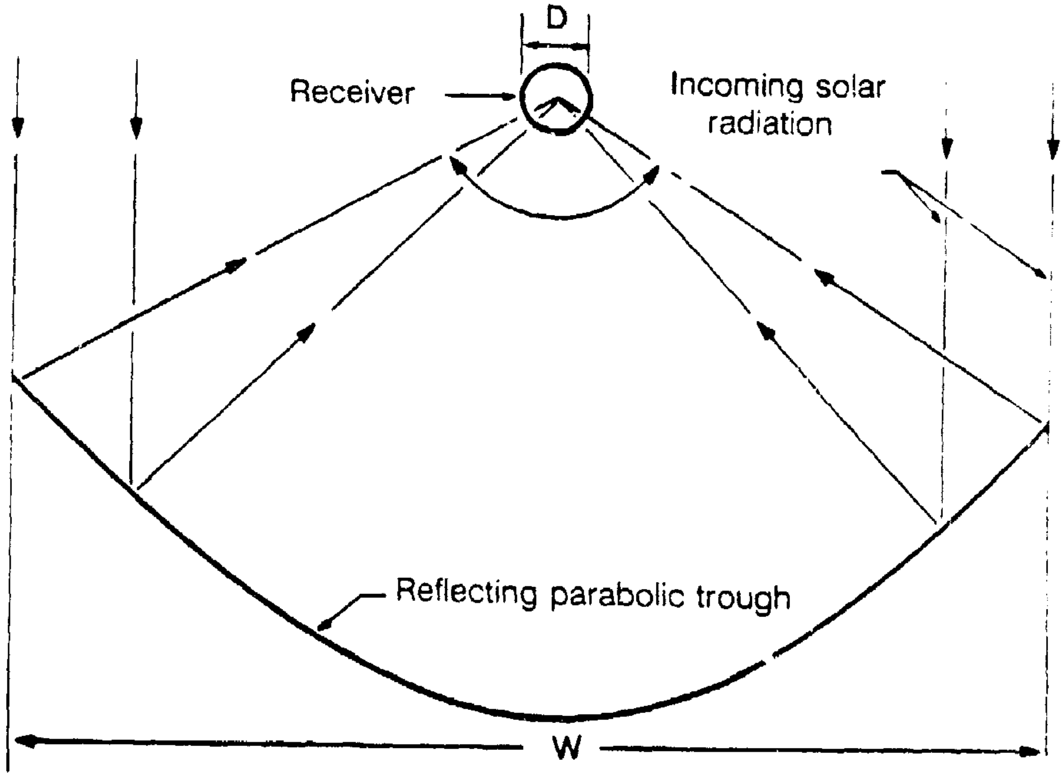


Figure B.3.3. Concentrating solar collector.(2)

One of the major disadvantages of a fixed position is the cosine loss of power at off-noon hours. The cosine loss is zero at solar noon when the sun's rays impinge directly on the aperture area perpendicularly and the loss increases before or afterwards when the sun's rays are focused "upstream" or "downstream" of the point where they are reflected from the reflector. Although this method of operation is the simplest, output from the collector only occurs when the reflected rays are focused on the receiver. During the spring and fall of the year, solar altitude changes most rapidly on a day-to-day basis, and the tilt of the trough would have to be adjusted more frequently. Usually, it is desirable to adjust the tilt so focusing is perfect at about 1 to 1/2 hours before solar noon, so the sun's rays stay focused on the receiver for 4 to 6 hours per day. A schematic diagram of a solar-assisted culvert thawing device is shown in figure B.3.4.

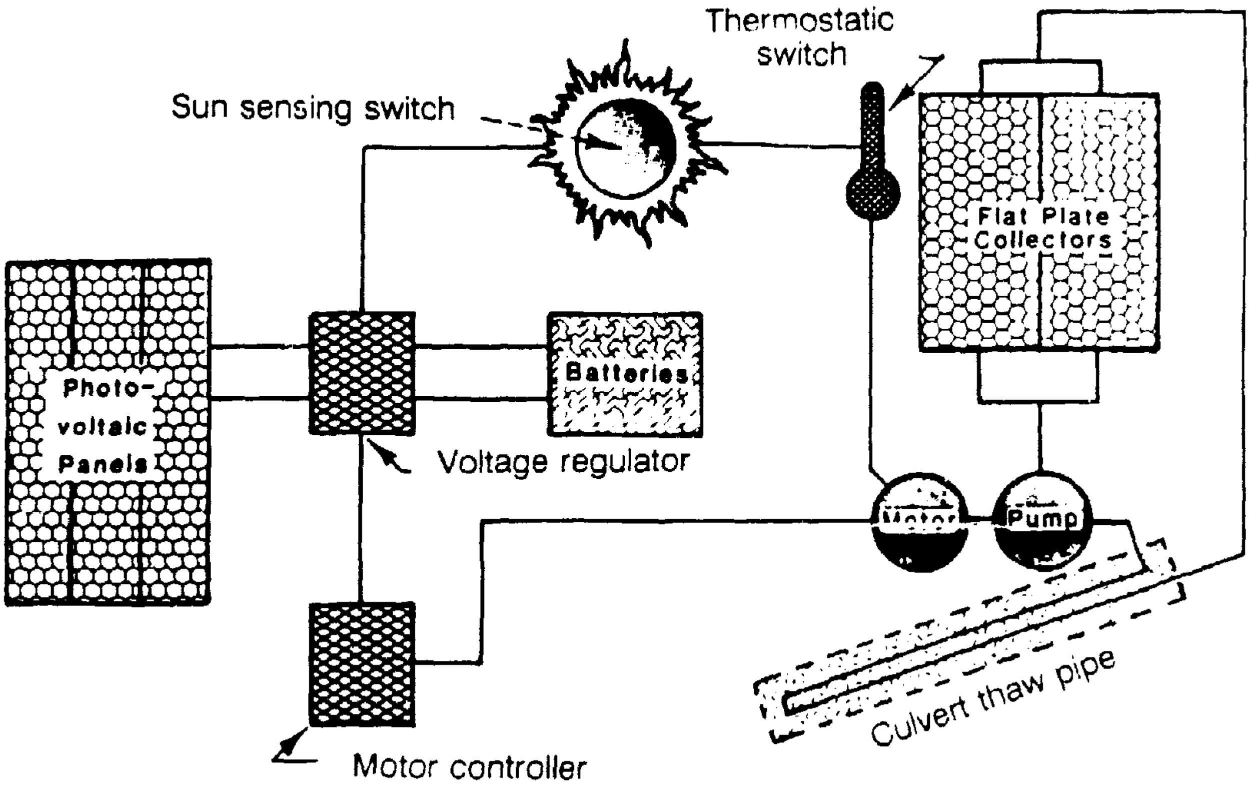


Figure B.3.4. Schematic diagram of solar assisted culvert thawing device.[2]

Thawing of ice-plugged culverts using solar energy can be cost effective when used under the right conditions. Because these devices are dependent upon sunlight and require a modest first cost, it is recommended that solar culvert thawing devices be used only when the following conditions are met:

1. Electrical power is not readily available.

2. Ice buildup occurs during the spring months.

3. Repeated thawing of the culvert is required.

4. The horizon is sufficiently low to allow exposure to sunlight.

SAFETY PRECAUTIONS

The potential of problems and injury relating to the process of thawing frozen culverts should be recognized and avoided. Improper use and/or accidents with high-pressure hot antifreeze-water solutions and fuel-oil fired heating systems can cause serious injury.

RESOURCE COMMITMENT = *:	5 Heavy	4	3 Medium	2	1 Low
COST RELATIVE TO REPLACEMENT = *:	5 High	4	3 Medium	2	1 Low

*Varies according to procedure selected.

REFERENCES

1. John P. Zarling and Fred A. Miller, *Solar Assisted Thawing Device - Phase I*, University of Alaska, Fairbanks, Alaska, November 1981.

2. John P. Zarling and Douglas H. Murray, *Solar Assisted Thawing Device - Phase II,* Alaska DOT Report AK-RD-83-36, University of Fairbanks, Alaska, May 1983.

APPENDIX B-4. PROCEDURE FOR CLEANING AND REPAIRING LINED DITCHES

APPLICATIONS

This procedure applies to the cleaning of lined ditches.

COMMENTS

Water creates many serious problems for all types of roads. Water that does not drain properly from paved roads will accumulate in the base and subgrade. This accumulation weakens the base and causes critical surface defects such as potholes and area cracking. Such surface defects, in turn, cause further deterioration of the road and can create safety hazards for traffic. Poor surface drainage on unpaved roads can cause potholes, soft spots, ruts, and corrugations. Water saturation can even weaken the adjacent embankment. Clogged drainage structures contribute to water saturation problems. Regular ditch maintenance will help prevent these problems and more expensive road repairs.

The best time to inspect ditches is before and after the rainy season. Examine ditches before the rainy season to make sure they are in good condition and that water will be able to flow freely through them. Examine ditches after the rainy season in order to schedule cleaning to remove accumulated sediment and debris.

The equipment needed to perform this maintenance function includes a dump truck to haul the hand tools and crew to the work site. Hand tools needed include rakes, hoes, shovels, pick axes, grass-cutting tools, a stringline, rope, bucket, a pole, a hand tamper, paint, and a wheelbarrow.

Cleaning lined ditches by hand is the best method because it will not damage the ditch lining. Hand cleaning is easy to schedule and perform because no material or heavy equipment is required. Cleaning drainage structures by hand also allows time to completely inspect the area for damage and possible future problems. A gradall may be required where the amount of sediment is excessive.

PROCEDURES

Several factors contribute to correctly performed, long-lasting maintenance work. They are proper planning by a supervisor, proper on-site supervision, and use of a skilled, conscientious work crew. Unless all of these factors are considered, the work may be poorly done and will probably have to be repeated.

The following information covers each work step in detail. Equipment and hand tools also will be covered.

1. Place traffic control devices if required. The goal is to keep the disruption of traffic flow to a minimum while furnishing the maximum safety for the crew and the motoring public. Place advance warning signs and traffic control devices. Position flaggers at appropriate positions if required. Keep tools off the roadway.

2. Assign the work. Distribute the work in a way that will reduce the need to cross the road. Instruct the crew to move forward as a unit with each worker cleaning the area in front of him.

3. Remove and dispose of all debris and obstructions, working from downstream up. Use shovels to move rocks, trash, and earth to the shoulder of the road. Load the waste material into a wheel barrow. Do not leave it near any drainage structure. Keep the roadway shoulders clean. If waste material cannot be disposed of nearby, load it onto a dump truck and carry it to a predetermined disposal site.

   When working on masonry or stonelined ditches, remove all vegetation such as grass, plants, and shrubs. Their roots can break up the ditch lining and block the flow of water.

4. Inspect for damage. Check the flow to see that there are no high or low spots. Check the ditch lining to see if there are any broken pieces of concrete or missing sections of masonry. If a major defect is located that cannot be repaired by the crew, mark the spot so that it is visible from the road. Use paint. Report the defect to the supervisor so that repairs can be scheduled.

5. Make minor repairs. Replace and compact backfill behind lined ditches if it is eroded.

6. Clean the work site. Remove all waste material from the shoulders. Inspect, clean, and load all hand tools. Remove traffic control devices by loading them in reverse order of their placement.

SAFETY PRECAUTIONS

As with all maintenance operations, safety is of prime importance. The appropriate personal protection equipment and/or clothing should be worn or used. This would include a hard hat, gloves, heavy high-top shoes or work boots, and a safety vest.

RESOURCE COMMITMENT =1: 5 4 3 2 1
Heavy Medium Low

COST RELATIVE TO
REPLACEMENT = 1: 5 4 3 2 1
High Medium Low

REFERENCES

1. *Guide to Common Road and Equipment Maintenance Procedures*, Louisiana Transportation Research Center, Louisiana State University Baton Rouge, Louisiana, 1989.

APPENDIX B-5. PROCEDURE FOR MECHANICAL CLEANING AND REPAIR OF UNLINED DITCHES

APPLICATIONS

This procedure applies to the mechanical cleaning of unlined ditches.

COMMENTS

An important consideration for a roadway is the removal of water away from the pavement. Ditches adjacent to the road permit surface and underground water to collect and drain away from the roadbed. Ditches also intercept water from the surrounding area and carry it away. After a period of time these ditches may collect large amounts of sediment or debris and may become overgrown with heavy vegetation. This interferes with the proper flow of water in the ditches and culverts and the drains that connect them. Water that does not drain away properly will soak the base material of the roadbed and cause serious maintenance problems such as potholes, cracking, settling, depressions, or a complete surface failure. Regular ditch maintenance will help prevent water saturation problems and more expensive road repairs.

It is important to understand the structure of the ditch and how it functions to protect the road and adjacent property.

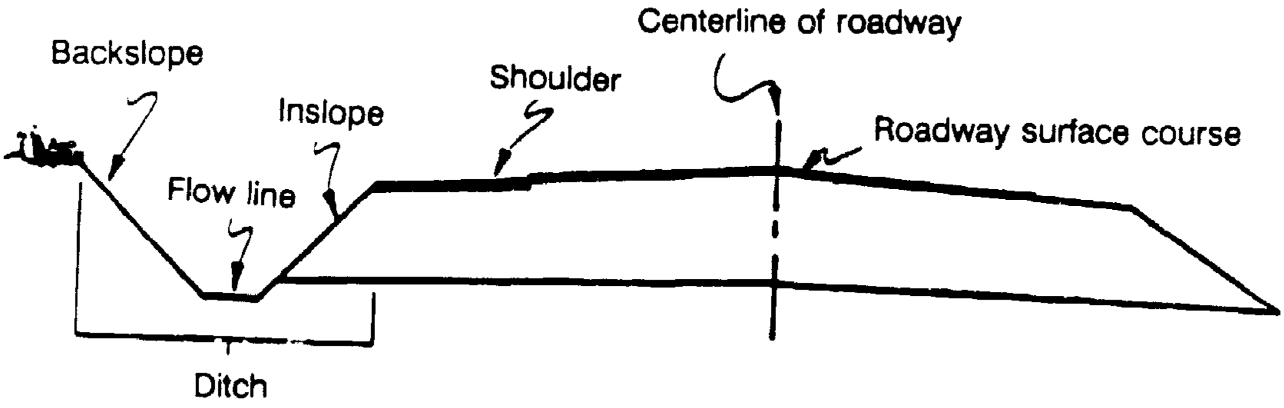


Figure B.5.1. Structure of roadway ditch.

The four parts of an unlined ditch are the road shoulder, the ditch inslope (foreslope), the ditch backslope, and the ditch flow line. The road shoulder is the surface area beside the traffic lane that drains the rain from the roadway surface. The ditch inslope (foreslope) provides an additional incline that keeps water moving away from the roadway shoulder. The ditch backslope is the opposite side of the inslope and is the side farthest away from the roadway. The backslope provides the incline that drains water from adjacent land to the bottom of the ditch. The bottom of the ditch is called the ditch flow line. The flow line allows water deposited in the ditch to flow smoothly along the ditch to outlets. All four parts of a ditch work together to drain water away from the roadway.

Mechanical ditch cleaning can be done with a motor grader or a machine shovel. The type of equipment used depends on the condition of the ditch and the availability of the equipment.

Use a motor grader if the following conditions are met:

- The ground adjacent to the ditch is solid enough to support heavy equipment.
- The ditch inslope and backslope are sloped gradually enough to allow the motor grader easy access.
- The ditch is long.
- The ditch is not interrupted by drain pipes or culverts.

Use a machine shovel if the following conditions are met:

- If there is excessive water causing the slopes to be too soft to support heavy equipment.
- If the inslope and backslope are too steep for easy access.
- When the ditch is frequently interrupted by drain pipes or culverts.

PROCEDURES

Plan the job well in advance. Make a thorough visual inspection of the work site. Determine if the ground is firm enough to support heavy equipment. Decide what the grade of the inslope and backslope should be. Locate culverts pipes and outfall ditches.

Consider the type and capability of the equipment. Cleaning procedures may vary according to equipment capabilities.

Decide how and where to dispose of the material that will be removed from the ditch. If the waste material is spread on the adjacent right-of-way, it should be placed beyond the beginning of the backslope to avoid being washed back into the ditch.

The following are general guidelines for the mechanical cleaning of unlined ditches:

1. Place traffic control devices to keep the disruption of the traffic flow to a minimum while furnishing maximum safety for the crew and the motoring public. Place advance warning signs and traffic control devices. Position flaggers at appropriate positions if circumstances require.

2. Clean the ditch, working from downstream up.

   If using a motor grader:

   a. Make a preliminary pass with the motor grader to clear out vegetation.

   b. Clean the inslope. Position the motor grader blade so that its edge touches the bottom of the ditch at the flow line. Be sure the blade is set to the proper predetermined grade. Move forward to cut along the flow line to remove mud, silt, and other accumulated debris from the bottom of the ditch.

   c. Clean the backslope. Position the motor grader over the inslope with the opposite edge of the blade now touching the ditch bottom. This cut redefines the ditch shape on the backslope side and establishes the flow line at the bottom of the ditch.

   If using a machine shovel:

   a. Be sure the excavator is on firm ground before reaching down into the ditch to remove debris.

   b. Load excess material directly into a dump truck.

   c. Take care in reestablishing the ditch flow line.

3. Clean the adjacent culvert inlets, outlets, and outfall ditches. Clean by hand. Cut down the heavy vegetation and plant growth. Shovel the accumulated debris away from the ditch, making sure the material will not wash back in. Clean all the outfall ditches that connect to the main ditch. Clean culverts or pipes that drain water from the main ditch.

   Clear all pipe openings but maintain the proper contour and shape of the ditch at culvert inlets and outlets, as well as the proper flow path.

4. Properly dispose of unwanted material.

5. Clean the work site and the road surface of unwanted material.

6. Inspect the finished job. Check the ditch flow line. Be sure the flow line is uniform with no low or high spots. Check the ditch contour for smooth slopes and unobstructed outfall ditches, culverts, and pipes.

7. Remove the equipment from the work site.

SAFETY PRECAUTIONS

As with all maintenance operations, safety is of prime importance. The appropriate personal protection equipment and/or clothing should be worn or used. This would include a hard hat, gloves, heavy high-top shoes or work boots, and a safety vest.

RESOURCE COMMITMENT = 1:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. *Guide to Common Road and Equipment Maintenance Procedures,* Louisiana Transportation Research Center, Louisiana State University, Baton Rouge, Louisiana, 1989.

APPENDIX B-6. PROCEDURES FOR VEGETATIVE STREAMBANK STABILIZATION

APPLICATIONS

Vegetation may be used to stabilize and protect streambanks from erosion in creeks and streams in the vicinity of culvert installations.

COMMENTS

This material is taken from procedures presented in the *Virginia Erosion and Sediment Control Handbook.*(1)

The utilization of living plants instead of or in conjunction with structural solutions has many advantages. The degree of protection increases as the plants grow and spread. The repair and maintenance of structures is unnecessary where self-maintaining streambanks are established. The protection provided by natural vegetation is more reliable and effective when the cover consists of natural plants native to the site.

At the edge of all natural watercourses, plant communities exist in a characteristic succession of vegetative zones, the boundaries of which are dependent upon site conditions, such as the steepness and shape of the bank and the seasonal and local variation in water depth and flow rate. Streambanks commonly exhibit the following zonation as shown in figure B.6.1.

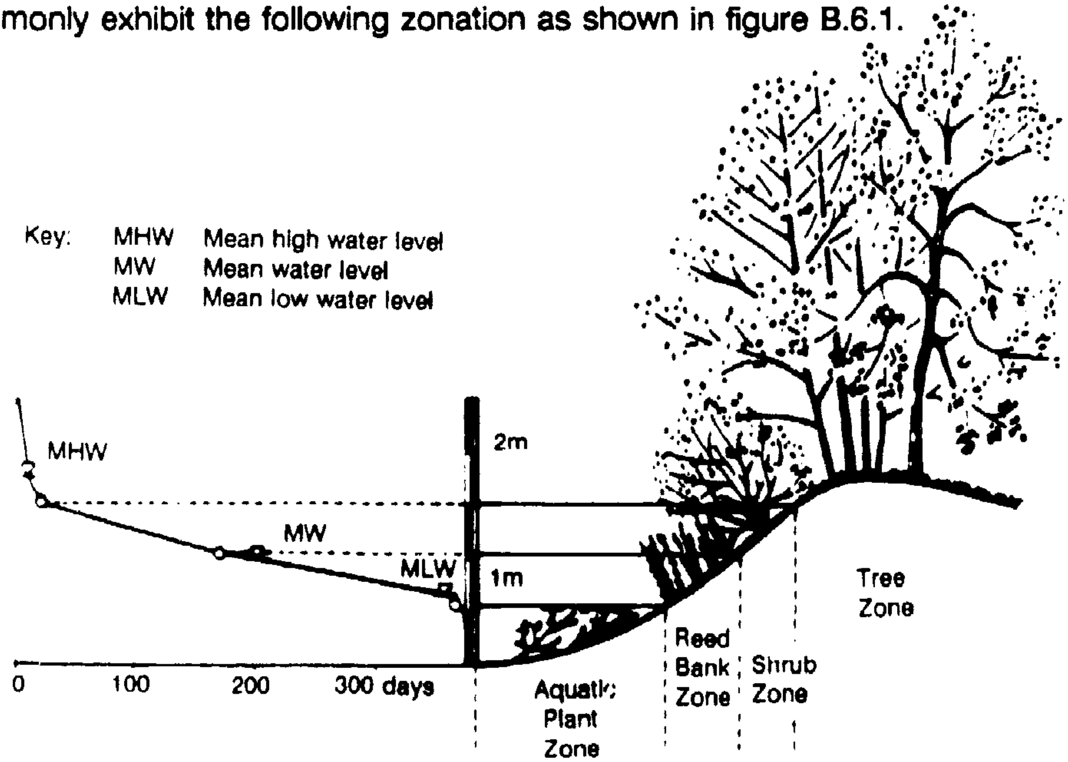


Figure B.6.1. Typical annual curve of water levels correlated with typical vegetative zones.(1)

1. Aquatic plant zone - This zone is permanently submerged. The roots of plants, such as water lilies, reduce the water's flow rate by friction and help bind the soil. These plants further protect the channel from erosion because the water flow tends to flatten them against the banks and bed of the stream.

2. Reed-bank zone - The lower part of this zone is normally submerged about half the year. Plants, such as rushes, cattails, and reed grasses, grow in this area. Their roots bind the soil and the growth slows the flow rate of the water by friction.

3. Shrub zone - This zone is flooded only during periods of high water. It is inhabited by trees and shrubs with a high regenerative capacity. These plants also hold the soil with their roots and slow the water by friction. The shrubs protect tree trunks from damage caused by breaking ice and help to prevent the formation of strong eddies around large trees during flood flows. Shrub zone vegetation is particularly beneficial along the impact bank of a stream meander, where maximum scour tends to occur.

4. Tree zone - This zone is flooded only during periods of very high water. These trees hold soil in place with their root system.

The aquatic plant zone is difficult to implant and establish artificially; however, it tends to become established naturally when the reed-bank vegetation is present. The tree zone is least significant in terms of protecting banks. Therefore, guidelines will be presented only for the reed-bank and shrub zones. These guidelines do not apply in tidal waterways.

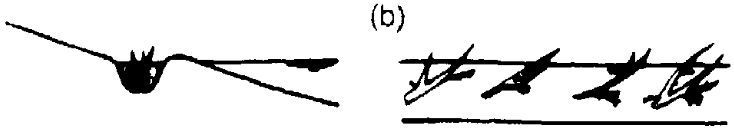
PROCEDURES

1. Establishing reed bank protection: Local agencies, the U.S. Forest Service, or local U.S. Corps of Engineers Offices should be contacted to obtain the types of native plants that thrive in this zone. The four following common plants are considered suitable:

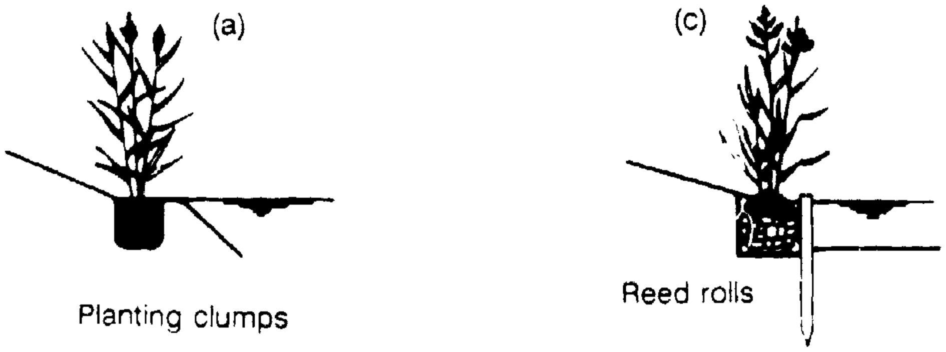
    - Common Reed (Phragmites communis)
    - Great Bulrush (Scirpus lacustris)
    - Reed Canary Grass (Phalaris arundinacae)
    - Common Cattail (Typha latifolia)

The greatest protection of the four listed is the Common Reed, although it will not be native to all areas.

There are several methods of planting reed-bank protection, as shown in figure B.6.2.



Planting stem slips



Planting clumps

Reed rolls

Figure B.6.2. Methods of establishing reed-bank vegetation.[2]

a. Planting in clumps: The oldest and most common method of planting reeds is planting in clumps, shown in figure B.6.2(a). The stems of the reed colony are scythed. Square clumps are cut out of the ground and placed in pits in the bank. The clumps are planted at a depth so that they will be submerged to two-thirds their height.

b. Planting rhizomes and shoots: Less material is needed for planting rhizomes and shoots. A rhizome is a fleshy plant stem that grows horizontally under or along the ground, sending out roots below and shoots or leaves above. Slips are taken from existing beds during the dormant season, after the stems have been cut. They should be handled carefully to avoid bruising the buds or tips of the sprouts. They are placed in holes or narrow trenches, along the line of the average summer water level, so that only the stem sprouts are showing above the soil.

c. Planting stem slips: It is also possible to plant stem slips along slow-moving streams, as shown in figure B.6.2 (b). Usually, three slips are set in a pit 12 to 20 inches deep. The pits should be located one foot apart.

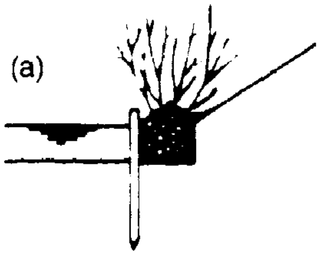
d. Reed rolls: The fastest and most effective method of establishing reed-bank vegetation is the use of reed rolls, as shown in figure B.6.2 (c), in which the protection of the bank is, at first, ensured by placement of structural materials. A trench 18 inches wide is dug behind a row of stakes. Wire netting, such as 1/2-inch hardware cloth, is stretched from both sides of the trench between upright planks. Onto this netting is dumped fill material, such as coarse gravel, sod, or soil and other organic material. This material is then covered by reed clumps until the two edges of the wire netting can just be held together by wire. The upper edges of the roll should be no more than two inches above the level of the water. Finally, the planks are taken out, and any gaps along the sides of the roll are filled in with earth. This method provides greater protection from the possibility of a heavy flow washing away the vegetative materials before they have a chance to become established.

e. Seeding: Some grasses can be sown on very damp bank soil provided that the seeded surface is not covered by water for six months after sowing. Cool-season grass should not be seeded in the summer.

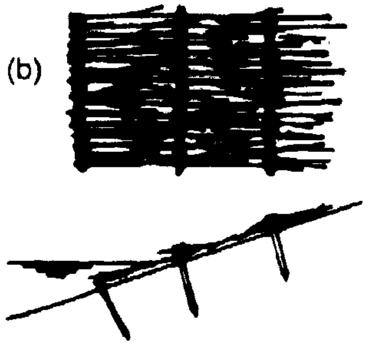
f. Vegetation and stone facings: Reed-bank vegetation can be planted in conjunction with riprap or other stone facing. Clumps, rhizomes, or shoots can be planted in the crevices or gaps along the line of the average summer water level.

2. Establishing shrub zone vegetation: Stands of full-grown trees are of little use for protecting streambanks apart from binding the soil with their roots. Shrubwood provides much better protection. Plants should be used that are well adapted to the stream and site conditions. Methods of establishing shrub zone vegetation is shown in figure B.6.3.

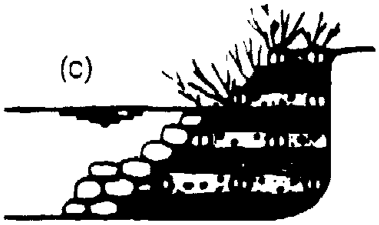
   a. Seeding and sodding: If the streambed is small and a good seedbed can be prepared, grasses can be used alone to stabilize the streambed. Seeding mixtures should be selected and operations performed according to local specifications. An erosion blanket, such as jute netting or excelsior blankets, should be installed according to normally accepted specifications for the locality. Sod can also be placed in areas where grass is suitable.



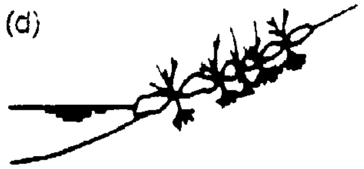
Fascine roll



Willow mattress



Packed fascine work



Cuttings between riprap

Figure B.6.3. Methods of establishing shrub-zone vegetation.(2)

Sod should be selected and placed according to area specifications. Turf should be used only where the grass will provide adequate protection, necessary maintenance can be provided, and establishment of other streambank vegetation is not practical or possible.

b. Plant cuttings and seedings: Some shrubs, native to the specific area, can be put into the soil as cuttings. They can usually be planted as one-year-old stock or as fresh hardwood cuttings gathered from local mother-stock plants.

Streambeds are often difficult to plant, even when they are well sloped. The best tool for planting in these areas is a dibble bar, a heavy metal tool with a blade and a foot pedal. It is thrust into the ground to make a hole for the plant, as shown in figure B.6.4. Local standards and specifications should be followed for selection of plants and planting techniques.

c. Fascine rolls: Fascine rolls are bundles of brushwood or sticks, without branches if possible, that are filled with coarse gravel and rubble and wired tightly around the outside. They are 4 to 20 yards long and 4 to 16 inches in diameter. They are set against the bank so that the parts that are to take root touch the ground above the water level and are able to get sufficient moisture. Covering with earth improves the contact with the ground and retards the loss of moisture from the wood. Fascine rolls are illustrated in figure B.6.3.(a).

d. Willow mattresses: The degree of stream-bank protection can be increased by using willow mattresses, if willow is available, or packed fascine work. Willow mattresses consist of four-to-eight-inch-thick layers of growing branches set perpendicular to the direction of the current or sloping downstream, with the broad end of the branches oriented downstream. The branches are held together with interweaving wire at intervals of 24 to 32 inches, as shown in figure B.6.3.(b). The whole mattress structure should be covered with two to ten inches of earth or fine gravel.

e. Packed fascine work: Packed fascine work, as illustrated in figure B.6.3.(c), consists essentially of layers of branches laid one across the other to a depth of 8 to 12 inches and covered with fascine rolls. The spaces between the fascine rolls are filled with gravel, stones, and soil so that no gaps remain and a layer of soil 8 to 12 inches is added on top. Packed fascine work is particularly suitable for repairing large breaches in the banks of streams with high water levels.

f. Combination with stone facing: In many places, the bank is not adequately protected until the roots are fully developed, and temporary protection must be provided by inanimate materials. One method is the planting of woody plants in the crevices of stone facing as shown in figure B.6.3.(d).

DIBBLE PLANTING

1. Insert dibble at angle and push forward to upright position.

2. Remove dibble and place seedling at correct depth.

3. Insert dibble 2 inches toward planter from seedling.

4. Pull handle of dibble toward planter firming soil at bottom of roots.

5. Push handle of dibble forward from planter firming soil at top of roots.

6. Insert dibble 2 inches from last hole.

7. Push forward then pull backward filling hole.

8. Fill in last hole by stamping with heel.

9. Firm soil around seedling with feet.

Figure B.6.4. Dibble planting.(3)

SAFETY PRECAUTIONS

Streambanks are always vulnerable to new damage. Repairs are needed periodically. Banks should be checked after every high-water event is over. Gaps in the vegetative cover should be repaired at once with new plants and mulched if necessary. Fresh cuttings from other plants on the bank can be used, or they can be taken from mother-stock plantings if they are available. Trees that are established on the bank should be removed at once.

RESOURCE COMMITMENT = 3:	5 Heavy	4	3 Medium	2	1 Low
COST RELATIVE TO REPLACEMENT = 1:	5 High	4	3 Medium	2	1 Low

REFERENCES

1. *Virginia Erosion and Sediment Control Handbook*, Virginia Department of Conservation and Historic Resources, Division of Soil and Water Conservation, Richmond, Virginia, 1980.

2. P. Seibert *Importance of Natural Vegetation for the Protection of the Banks of Streams, Rivers, and Canals in Freshwater*, pp. 35-67, Council of Europe, New York, 1968.

3. *A Guide for Vegetating Surface-Mined Lands for Wildlife in Eastern Kentucky and West Virginia*, U.S. Department of the Interior, Fish and Wildlife Service.

APPENDIX B-7. PROCEDURES FOR THE SELECTION AND USE OF EROSION CONTROL GEOTEXTILES

APPLICATIONS

Geotextiles and related geosynthetic materials have many known uses. New innovative applications continue to emerge. Applications for culvert repair practices discussed in this section are concerned with slope stabilization, filtration, and erosion control.

The Geotextile Division of the Industrial Fabric Association International, in their publication *A Design Primer: Geotextiles and Related Materials*,(1) lists the application areas and functions for performance of four types of geosynthetics, shown in table B.7.1. Material in this section has been taken from that publication.

Table B.7.1: Types of Geotextiles: Their Applications and Function(1)

Application Area	Geosynthetics Involved	Functions for Performance
Subgrade stabilization	GT,GG	S,R,F
Embankments over soft soils	GT,GG	R,S
Steep slope reinforcement	GG,GT	R
Retaining walls	GG,GT	R
Subsurface drainage & filtration	GT	F,S
Drainage-prefabricated composites	GC, GN	D,F,S,B
Erosion control via turf reinforcement	GC	R,S
Erosion control via rip rap (armor)	GT	F,S
Erosion control via fabric-forming mats	GT	S,F
Sediment control using silt fence	GT	B,R,S
Geomembrane protection	GT	S,R

GT = geotextile
GG = geogrid
GC = geocomposite
GN = geonet

S = separation
R = reinforcement
F = filtration
D = drainage
B = barrier

The materials referred to are defined as follows:

- Geosynthetic - The general classification of all synthetic materials used in geotechnical engineering applications. This term includes geotextiles, geocells, geogrids, geomembranes, and geocomposites. All of these materials are generally used with foundation, soil, rock, earth, or any other geotechnical engineering-related material, as an integral part of a human-made project, structure, or system.

- Geotextile - Any permeable textile used in geotechnical engineering applications. Geotextiles are both woven and non-woven.

- Geomembrane - Serves as a liquid or vapor barrier and is, essentially, impermeable.

- Geogrid - An open-grid structure composed of filaments and strands of polymeric material, shaped in a right-angle grid pattern, and used primarily for grid reinforcement.

- Geocomposite - A manufactured material using geotextiles, geogrids, and/or geomembranes in laminated or composite form.

- Geonet - A three-dimensional, netlike polymeric material used for drainage in a geotechnical engineering application.

The different performance functions fulfilled by geotextiles are as follows:

- Separation - Acts as a partition between two adjacent materials.

- Reinforcement - Provides horizontal reinforcement layers in the soil.

- Filtration - Provides high permeability.

- Drainage - Holds the soil particles in place as the water flows freely out of the soil under gravity.

- Barrier - Hinders or restricts the passage of water.

Selection of the proper geotextile for a specific use is of major importance. In an effort to provide objective specification guidelines to end users, primarily State departments of transportation, a subcommittee was formed in 1982 by the Joint Committee on New Highway Materials. This subcommittee, referred to as Task Force 25, was convened to develop specifications for geotextiles in transportation.

The Joint Committee is made up of representatives from the American Association of State Highway and Transportation Officials (AASHTO), the Associated General Contractors of America (AGC), and the American Road and Transportation Builders' Association (ARTBA).

Approved specification guides have been developed for the following five applications:

- Paving fabric;
- Silt fence;
- Drainage geotextiles;
- Erosion control geotextiles; and
- Separation geotextiles.

This publication, referred to as TS25(2), is available from the Publications Department of AASHTO.

PROCEDURES

1. Geotextiles Used for Turf Reinforcement

Geotextiles are used to stabilize the soil while plant growth is established. The mat allows the roots and stems to grow through.

Description- Polymer erosion control mat linings are three-dimensional systems that can be used to establish a reinforced vegetative surface "turf" on streambanks, slopes, and in channels and ditches. The mat has adequate porosity to retain soil while allowing roots and stems to grow through. The mat entangles with the root and stem network of vegetation to greatly enhance its resistance to sheet, gully, and rill erosion. The system is flexible, can conform to irregular surfaces, and can prevent undermining. Top soil cover may be used to enhance temporary erosion protection and early vegetative growth. Specific application areas include the following:

- Slope protection;
- Channel banks;
- Roadside ditches;

- Conveying ditches; and
- Storm channels.

Turf reinforcement systems almost defy a simple physical description. Some of the variations are listed below.

- Entangled webbings of a three-dimensional structure;
- Open cells of a three-dimensional structure;
- Heavy woven fabrics consisting of thick filament fibers; and
- Various vegetative and non-vegetative filler materials within an open netting.

Installation- Turf-reinforcement systems are easily installed. However, the following are some of the precautions that should be taken when installing geotextiles. Manufacturer's literature is a good source of more detailed procedures.

- Slopes are covered with roll lengths going up and down the slope, i.e., no horizontal joints are permitted and vertical joints are shingled down stream.
- Ditch and channel bottoms are lined with longitudinal lengths. Joints perpendicular to water flow are shingled downstream with a 3-ft overlap.
- The edges of rolls are usually overlapped by 2 to 4 inches and suitably staked so as not to move with respect to one another. A minimum stake spacing of 5-ft is recommended at each edge.
- A geotextile filter should be placed beneath the turf reinforcement in areas of highly erodible soils. The matting is often bonded to the geotextile. If not, it must be secured by proper use of stakes.
- A soil or wood chip infill is often used with turf reinforcement for stability and seeding purposes.
- The upper and lower ends of turf reinforcement must be designed against undermining. Anchor trench details are shown in figure B.7.1.
- Material shall be placed loosely to allow contact with the soil. It must <u>not</u> be stretched.

2. Geotextiles Used with Riprap

Geotextiles are used between soil and riprap to prevent the erosion of soil through the armoring layer. The geotextile is used in lieu of a more conventional graded aggregate filter.

Description- Typical geotextiles used for this application are medium weight and strength non-woven fabrics, monofilament woven geotextiles, and some multifilament or fibrillated woven fabrics. There are three criteria that the geotextile must meet for use in this application. It must be:

- Sufficiently permeable to permit passage of water;
- Capable of retaining the soil particles beneath the armor without clogging; and
- Compatible with the general slope restraint needs, which may require both an acceptable soil-geotextile friction angle and adequate geotextile strength.

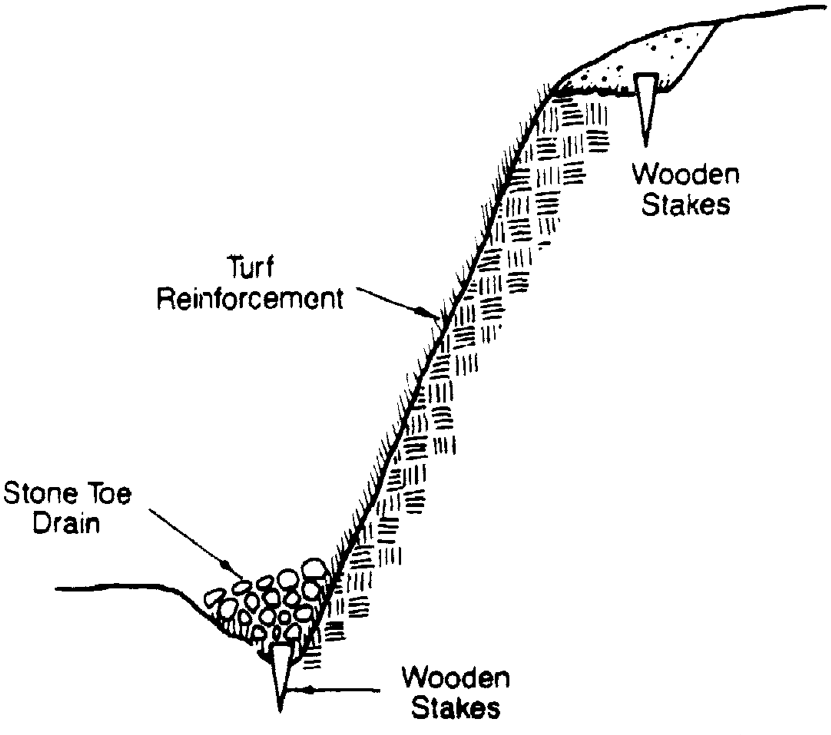


Figure B.7.1. Method of securing turf reinforcement.(1)

In some cases, the fabric is protected before riprap is placed on top of it by first using a sand or bedding stone cushion on the geotextile. This bedding layer, which is generally from three to six inches, provides the following benefits:

- Protects the geotextile during placement of the riprap;

- Provides an intimate contact between the geotextile and underlying soil;

- Provides protection against ultraviolet rays; and

- Protects against vandalism.

There are three design elements to be considered in using a geotextile. First, it must be adequate as a filter, which is a three-part problem. It must be adequate for flow, soil retention, and long-term clogging prevention. Second, since the gravitational force of the rock riprap may be partially transferred to the geotextile, an estimate of tensile strength is necessary. Third, the geotextile must be able to survive the installation stresses.

Installation - The formation of holes and the loss of tensile strength may result from dropping large stones on an exposed geotextile. Therefore, if height of drop cannot be controlled, either geotextiles with height-survivability properties must be specified or a bedding layer must be placed above the fabric.

Specific construction criteria should be followed for placing geotextiles between the soil layer and riprap:

1. Slopes steeper than 2.5 to 1 should not be used without laboratory testing to confirm stable soil-fabric friction angles.

2. Slopes should be graded to provide a smooth, fairly level surface. The fabric should be laid with the machine direction of the fabric placed parallel to the slope. Folds and wrinkles of the fabric should be avoided.

3. Adjacent rolls should be shingle-overlapped 12 inches in the down-slope or down-stream direction or should be seamed. Overlapped seams may be secured using metal pins as necessary.

   The Corp of Engineers specifies steel securing pins, nominally 3/16 inches in diameter, 18 inches long, pointed at one end and fitted with 1.5 inch diameter washers at the other end for use in securing fabrics in firm soils. The pin spacing is a function of the slope with the following spacings recommended:

Slope	Pin Spacing in All Directions
3:1	2 ft
3:1 to 4:1	3 ft
4:1	5 ft
>4:1	6 ft

4. The placement of stone cover should begin at the base of the slope and at the center of the geotextile-covered zone. The placement of the cover material may result in the tensioning of the underlying geotextile.

5. For fabrics having properties exceeding that required for soil-protected applications but without cushion, the height of drop for stones less that 250 pounds should be placed without free-fall.

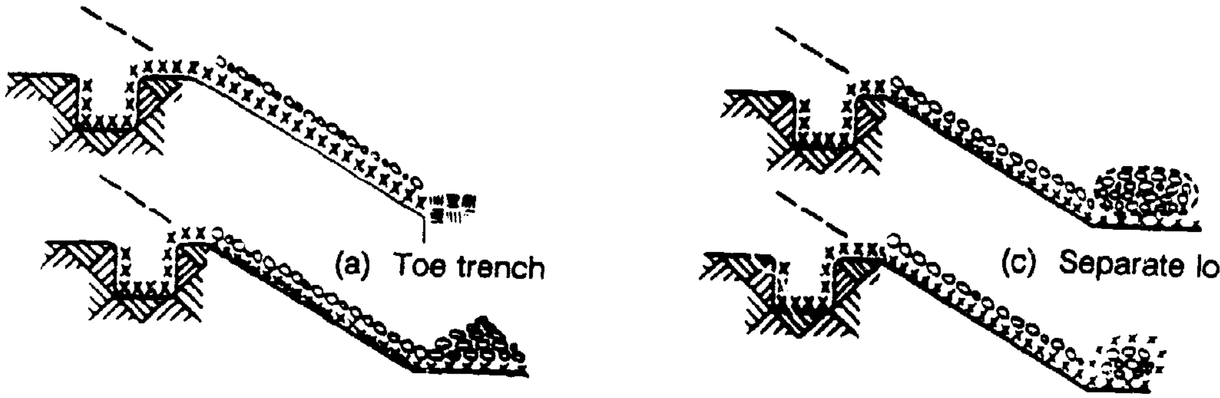
6. For fabrics with a sand cushion (i.e. protected) and fabrics having properties exceeding that for "unprotected" applications, the height of drop for stones less than 250 pounds should be placed with no free-fall.

7. If stones greater than 250 pounds must be dropped, or if a height of drop exceeding three feet must be used, field trials should be performed to determine the maximum height of safe drop that could occur without damaging the fabric.

8. Stone weighing in excess of 100 pounds should not be allowed to roll along the surface of the fabric.

9. Contouring of the stones should be achieved during their initial placement, with no grading of the stones after placement allowed.

The procedure followed for terminating the geotextile at the top and bottom of the slope or channel is important. If it is not secured properly, erosion can occur, the slope can be undermined, and the stability of the overlying system can be lost. Some successful methods for securing these ends are shown in figure B.7.2.



(a) Toe trench

(b) Gravity load

(c) Separate load

(d) Sausage wrapped

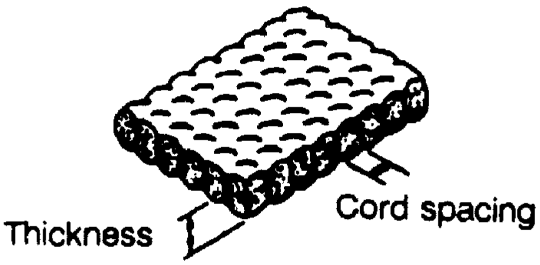
Figure B.7.2. Anchoring methods for geotextiles at toe of slope or embankment.(1)

3. Fabric Forming Systems

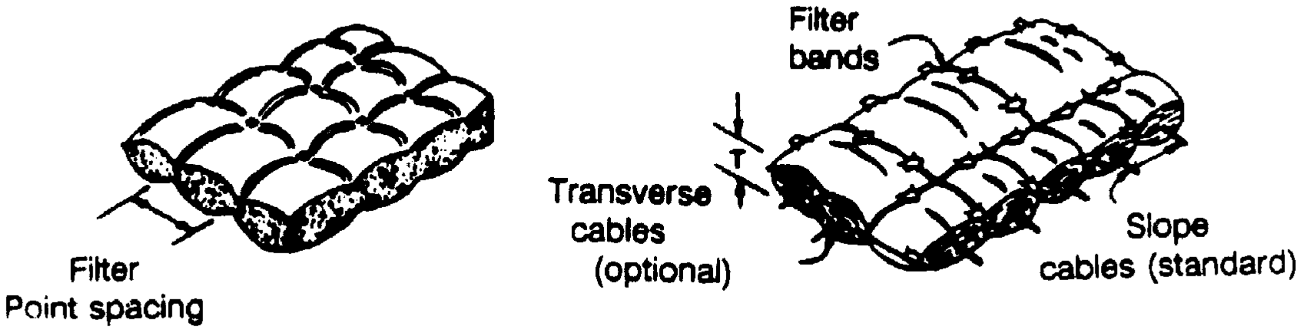
The traditional method of constructing formwork for concrete or grout is to use wooden or metal forms. Once these forms have been properly positioned, fluid concrete is placed in the forms and allowed to cure until it has sufficient strength of its own. While the constraint of a rigid form is important in some cases, it may be a distinct disadvantage in others.

Description - The use of fabrics as a forming system for erosion control of slopes and in drainage ditches is advantageous because it will conform to essentially any subsurface condition. Two sheets of water-permeable, double-layer fabric are joined together at discrete points. The fabrics are positioned on the area to be protected, where they are filled with a pumped, structural grout. The thickness and geometry of the mat are controlled by internal spacer threads woven into the upper and lower sheets of fabric.

The common styles are shown in figure B.7.3: uniform cross section, filter point, and articulating block. The filter points and filter bands between the blocks serve to dissipate pore water that is generated by ground water seeking to escape. The systems are available in varying thicknesses and spacings. The fabric enclosure must be capable of discharging any water within or beneath it, retaining the fill material, and having adequate strength to prevent rupture by the grout pressure.



(a) Uniform cross section



(b) Filter point

(c) Articulating block

Figure B.7.3. Typical cross section of fabric formed erosion control methods.(1)

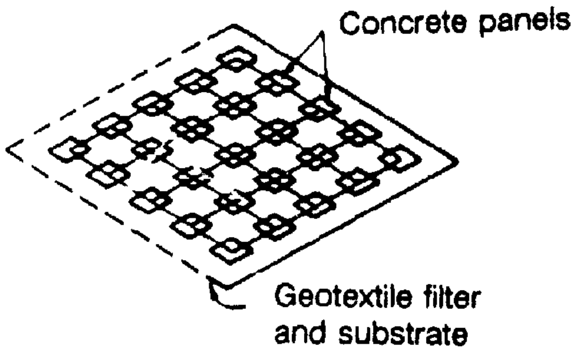
Installation - Methods of installation should follow the recommendations of the manufacturer. It should be noted that these systems also can be inflated under water, under conditions of flowing water, and in hazardous liquid environments.

Factory-fabricated systems also are available. In these cases, prefabricated concrete panels can be attached to a geotextile and an entire erosion control section manufactured, trucked to the site, and placed in a complete unit. Figure B.7.4. shows the types of prefabricated erosion control systems available.

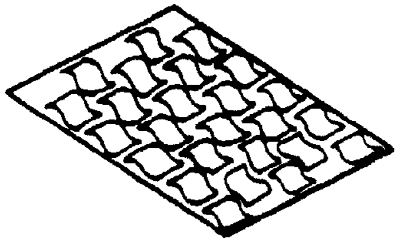
The Specification Guide for Erosion Control Geotextiles,(2) prepared by Task Force 25 Joint Committee on New Materials, AASHTO, is included in appendix C.

SAFETY PRECAUTIONS

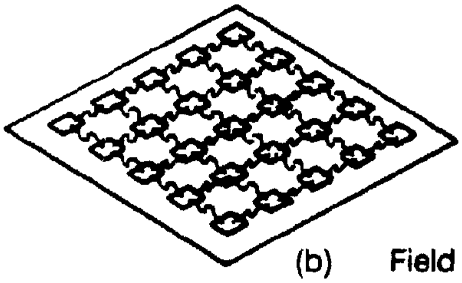
Material in this section has just skimmed the surface on the subject of the use of geotextiles for erosion control. One of the most common mistakes made is the selection of the wrong material for a particular application. Design procedures are not covered in this manual. Therefore, careful research should be done before a specific material is selected for use. *Designing with Geotextiles* (3) provides design procedures.



(a) Cable joined concrete panels fabricated in factory



(c) Interlocking concrete panels



(b) Field hooked concrete panel

Figure B.7.4. Various types of prefabricated erosion control systems.[1]

RESCOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. *A Design Primer: Geotextiles and Related Materials*, Geotextile Division, Industrial Fabrics Association International, St.Paul, MN, 1990.

2. *Task Force 25 Specification Guides*, TS25, Joint Committee on New Highway Materials, AASHTO, Washington, DC.

3. Koerner, R.M. *Designing with Geotextiles*, 2nd Edition, Prentice-Hall, Englewood Cliffs, N.J., 1990.

APPENDIX B-8. PROCEDURES FOR USE OF LOFFELSTEIN BLOCK TO PREVENT STREAMBANK EROSION

APPLICATIONS

Loffelstein block can be used to form retaining walls up to sixteen feet high. The system selected for inclusion in this manual is a related product, Waterloffel. Both of these are patented systems. Waterloffel can be used alone or in conjunction with other systems in the following applications:

- Channel and streambank lining for erosion control and retaining walls;
- Energy dissipation buckets when installed on the downstream face of water retaining embankments; and
- Protection against wave action when used on the upstream face of embankments.

COMMENTS

A Loffelstein module is a cast-concrete block with spoonlike hollows. The Waterloffel, which is designed to be used in water channels and on streambanks, includes interlocking wings or ears on each side of the unit that lock the modules together and prevent loss of fill material between the modules, as shown in figure B.8.1. They also have an additional crossmember that creates two independent troughs for the purpose of retaining backfill.

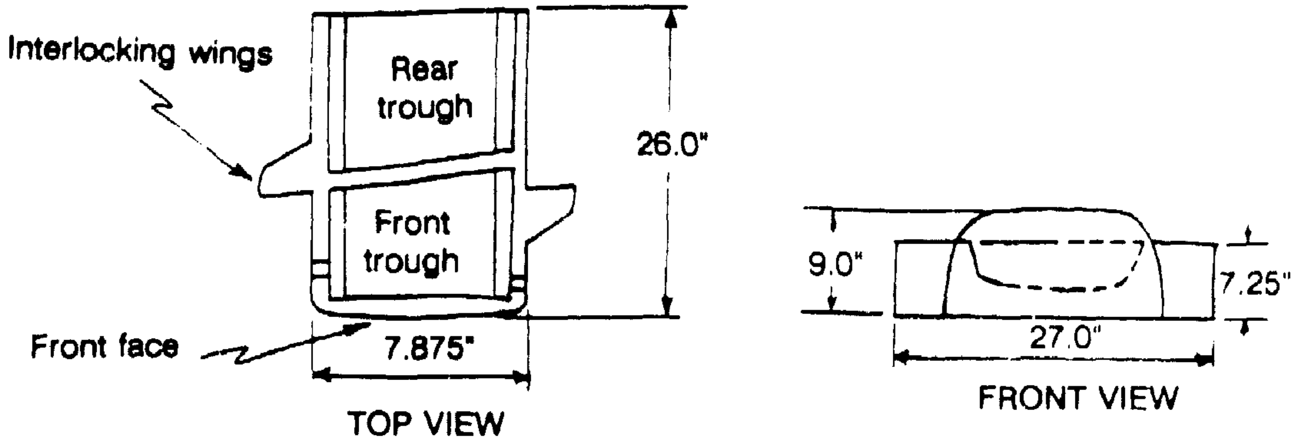


Figure B.8.1. Waterloffel module.[(2)]

PROCEDURES

The procedure outlined below for the installation of a Waterloffel retaining system is general in nature and will vary according to site conditions and design plans and specifications. Design procedures are available from the supplier.[1] Procedures may include, but may not be limited to, the following:[2]

1. Prepare the site by removing any vegetation such as shrubs or trees from the area that will be faced. A temporary roadway may need to be constructed to provide access for excavation equipment.

2. Prepare the subgrade to allow the pouring of a reinforced concrete footing. If the water level is above the proposed location of the footing, divert the stream to permit the pouring of the footing. Extend the footing the entire length of the wall.

3. If streambed conditions warrant, a base scour protection system should be placed to avoid undermining of the system. One method is to place a cellular confinement system such as GEOWEB on the prepared subgrade and fill with concrete. The system should extend the full length of the wall and approximately four feet from the face of the unit into the streambed channel.

4. While the concrete footing is still wet, slurry the first course of Waterloffel four inches deep into the footing. This provides the necessary toe for the retaining wall. The concrete footing serves two purposes: it provides a superior base if bearing soils are inadequate, and it also acts as a grade beam to ensure that the first course of the Waterloffel is level.

5. Place the Waterloffel modules side to side and front to back, according to the project plans. Employing a lifting device will promote a higher installation rate. The angle of set back is governed by the distance each Waterloffel is from the face of the previous course. Maintain the angle by using a chalk line, which is snapped at every course. Check for level on every second course during backfill.

6. At both the upstream and downstream side of the stream, key the Waterloffel into the slope by curving the wall convexly into the slope as each course is installed. This procedure is used to prevent water from entering behind the wall.

7. Proceeding up the wall, fill the dual troughs with clean rock as specified. Fill the area behind the modules with clean crushed rock or stone, as shown in figure B.8.2, to provide proper drainage of the existing soil behind the modules. Place a properly designed, non-woven filter fabric,

Figure B.8.2. Placement of a row of Waterloffel modules.

as specified, between the rock fill and the existing earth bank to prevent any migration of fines into the granular material.

8. Place additional erosion protection such as large boulders on the uncovered wall at each end of the wall.

9. Soil can be added to the face of the wall and planted with grasses, vines, or plants. Natural vegetation will occur over time since the troughs will trap silt and soil as water in the stream rises and falls. Figure B.8.3 shows a completed Waterloffel wall.

RESOURCE COMMITMENT = 4:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 2:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. Robert B. Rodgers, *Loffelstein Retaining Wall Design Manual*, Seagren Industries, Inc., St. Louis, MO.

2. "Waterloffel," *Loffelstein Retaining Walls*, Seagren Industries, Inc., St. Louis, MO.

APPENDIX B-9. PROCEDURES FOR ASSEMBLING AND INSTALLING GABIONS

APPLICATIONS

Gabions may be used to extend wingwalls and armor slopes against erosion. They also may be used as velocity attenuators.

COMMENTS

The use of gabions may be a simple and effective technique for stabilizing slopes against movement and erosion; protecting culvert headwalls, endwalls, and wingwalls from scour and undermining; and protecting streambeds against erosion due to high velocity water flow. They may be particularly effective where there is fast-moving water and riprap of the size or quality required is not available.

There are two types of gabion revetment designs that are distinguished by the shape and placement of the gabion: mattress and block. In the mattress design, the individual wire baskets are placed end-to-end and side-to-side to form a continuous mattress layer on a prepared bed or bank. The individual baskets are attached to each other and anchored to the base material. The wire baskets forming the mattress generally have a depth dimension that is much smaller than the width or length.

The block design is formed by stacking individual gabion blocks in a stepped fashion. Block gabions are typically rectangular or trapezoidal in shape and generally equadimensional. Design and construction information is available from manufacturer's literature.

Gabions may be cut or bent to form shapes to fit culvert appurtenances. The cut or bent edges of the mesh must be fastened securely to another part of the structure.

1. <u>Supply and Delivery</u>

Gabions are supplied folded flat and packed in bundles. For ease in handling, the number of gabions per bundle generally varies according to the size of the gabions. The lacing wire is supplied in coils.

2. <u>Stone</u>

Order only hard durable stone of the correct size range.

3. Assembly

a. Remove a single gabion from the bundle and proceed to unfold it on a hard flat surface. Stretch the gabion and stamp out the kinks, as shown in figure B.9.1.

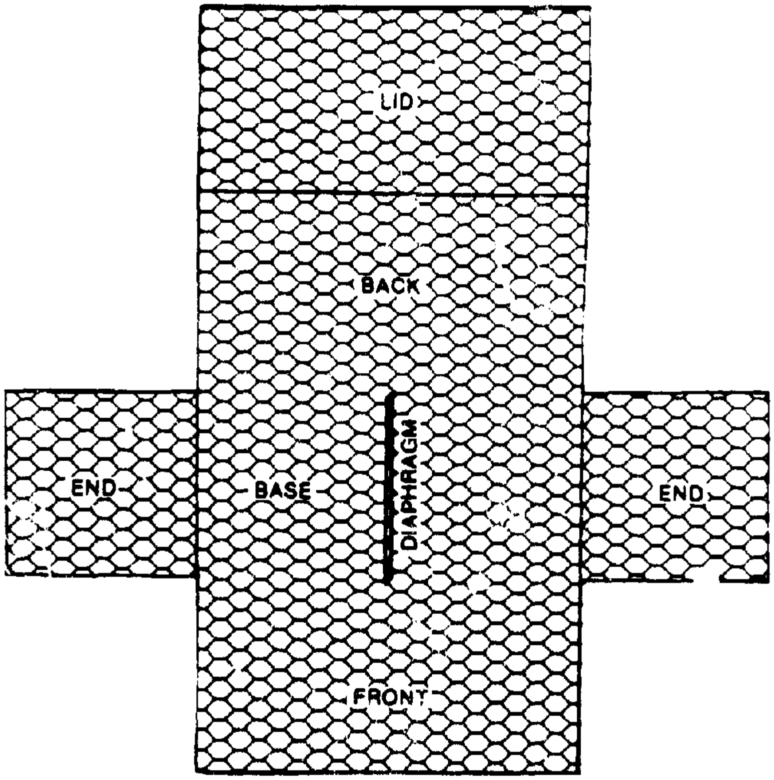


Figure B.9.1. Gabion baskets as supplied by the manufacturer.[1]

b. Fold the front and back panels to a right angle by stepping on the base along the crease.

c. Fold up the end panels and diaphragms and fasten them to the front and back panels, using the heavy gauge wire projecting from the upper corners of each panel. This procedure will ensure properly squared baskets with the tops of all panels even.

d. Securely lace all vertical edges of ends and diaphragms. Only connecting wire supplied by the manufacturer for this purpose should be used so that it will meet specification requirements.

e. To lace, cut a length of lacing wire approximately 1.5 times the distance to be laced, but not exceeding 5 feet. Secure the wire terminal at the corner by looping and twisting, then proceed lacing with single and double loops at approximately five-inch intervals as shown in figure B.9.2 Securely fasten the other lacing wire available from the manufacturer.

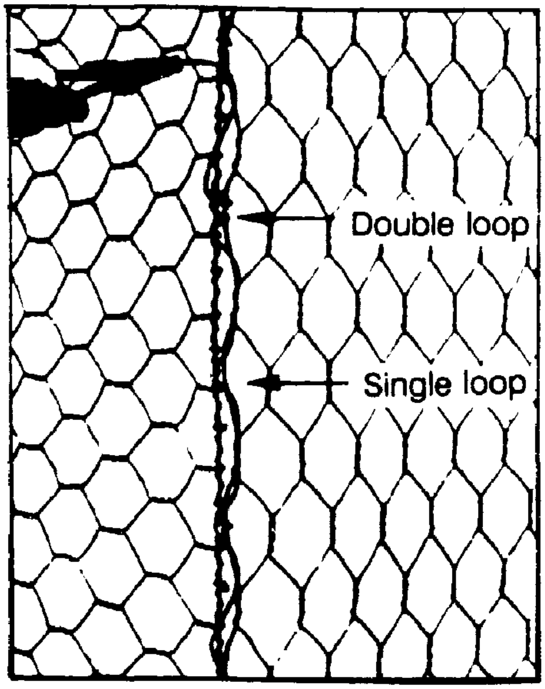


Figure B.9.2. Method of lacing vertical edges.(1)

4. Installation

a. Remove any unsuitable material below the location for the gabion baskets.

b. As required, replace unsuitable material with an acceptable granular material and thoroughly compact the entire foundation to a firm, even surface. When possible, locate the first row of gabions on bedrock. If this is not feasible, locate on natural ground or a compacted layer of hard, durable rock. The ground surface should be smooth and even.

c. Place specified geotextile fabric. The geotextile should be designed to allow passage of water while retaining in situ soil without clogging.

d. The assembled gabions are carried to the job site and placed in the proper location. To facilitate backfilling, place the gabions front to front and back to back, as illustrated in figure B.9.3, in order to expedite stone filling and lid lacing operations. (Note: Subassemblies consisting of as many gabions as can be handled by the crew at one time can be constructed at the yard. These subassemblies can be constructed during slack periods and kept on hand for future use).

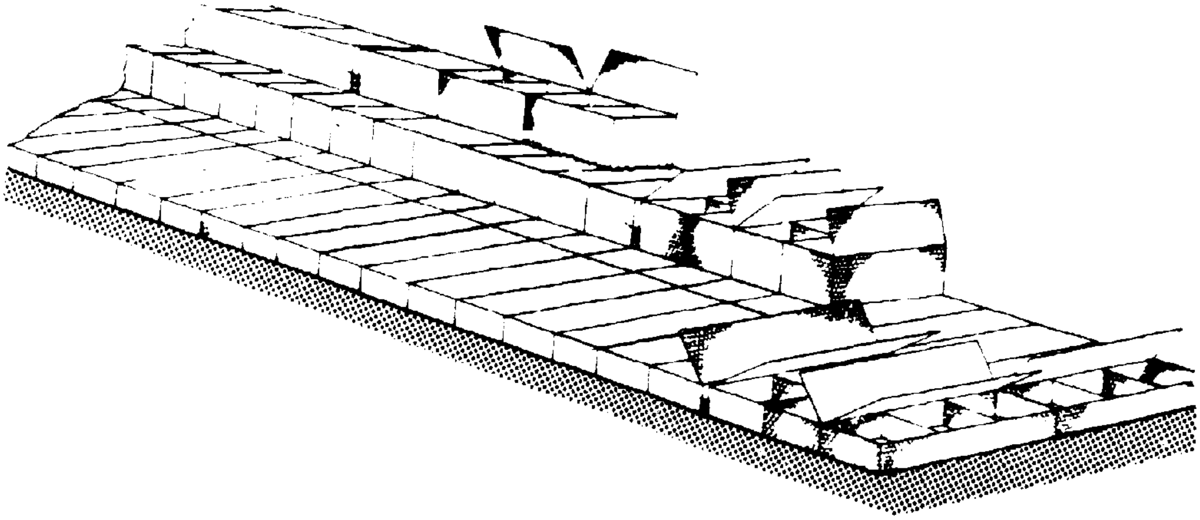


Figure B.9.3. Placement of gabions.[1]

e. Lace adjacent gabions along the perimeter of all contact surfaces. The base of the empty gabions placed on top of a completed row must also be tightly wired to the one below it.

f. In order to achieve proper alignment in large installations using gabions over three feet high, place the empty and laced gabions for a stretch of approximately 100 linear feet. Anchor the first gabion by partially filling it with stone. At the other end, apply tension with a come-along or other means, as shown in figure B.9.4. While the gabions are being stretched, inspect all the corners for open V's, which will result if corners were not properly fastened. Close any V's by relacing. Keep the gabions in tension while being filled. Leave the last gabion empty to allow for easily lacing the subsequent sub-assembly.

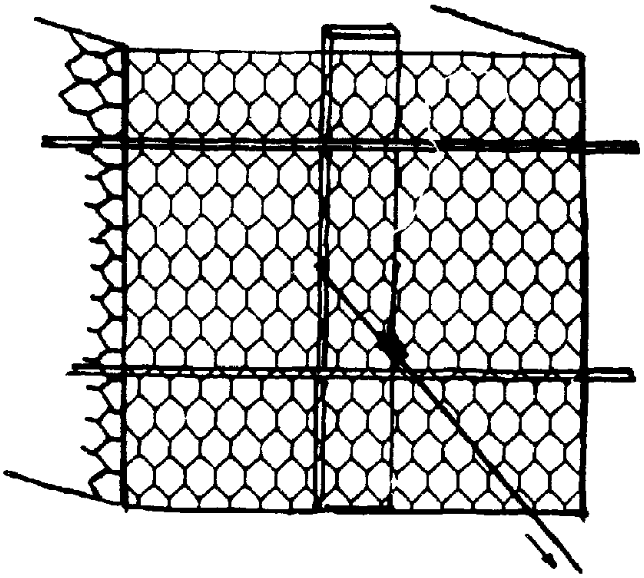


Figure B.9.4. Stretching gabions over three feet in height.[1]

5. Filling

   a. Fill each gabion with hard, durable rock that has been graded between 4 to 8 inches or as approved by the Engineer. The stone should be of a size sufficient to be retained within the mesh.

   b. Fill the gabions in lifts of one foot at a time. Place two connecting wires between each lift in each cell of all exposed faces and wire firmly as indicated in figures B.9.5 and B.9.6. Repeat until the gabion is completely filled. The last lift of stone should be level with the top of the gabion to properly close the lid and provide an even surface for the next course. The mesh must be stretched tight at all times.

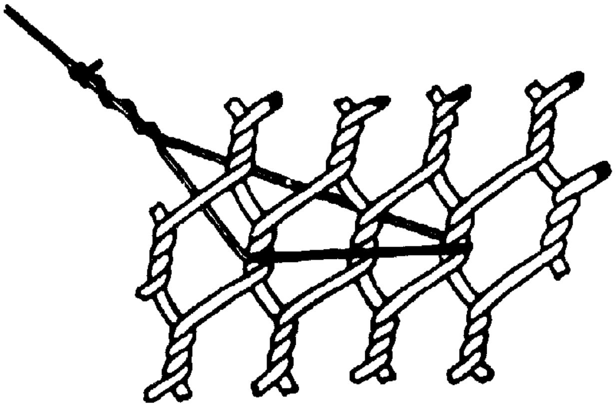


Figure B.9.5. Detail of connecting wires between lifts.(1)

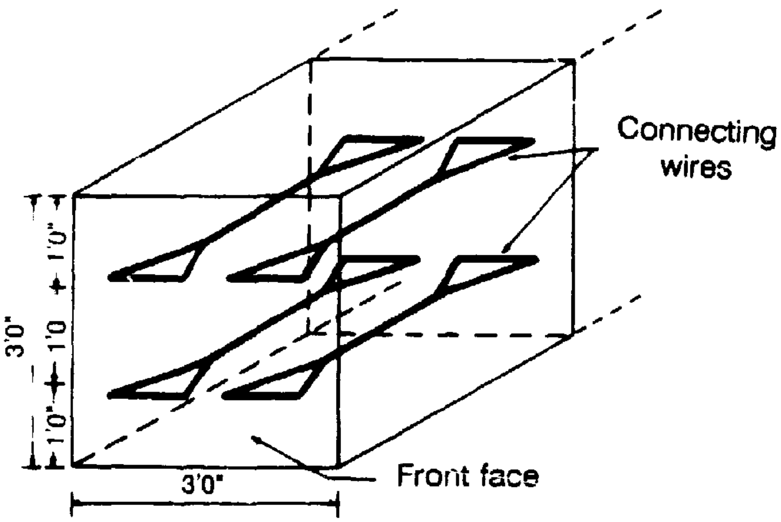


Figure B.9.6. Connecting wires between lifts.(1)

6. Mechanical Filling

a. When filling the gabions by machine, protect the top edges of the diaphragms and end panels from being bent or folded by the stone during placement. Rebars can be placed temporarily across the top edges of each mesh panel and laced to them to prevent movement. As an alternative, lengths of pliable metal can be bent into a V-shape and placed over the vertical panels to deflect the stone.

   b. During filling, dump the stone when the bucket is at its lowest practical position.

7. <u>Lid Closing</u>

   a. Fold the lid down along the hinge line so that the lid and gabion edges meet closely without gaps. Secure the lid at the corners and lace the lid shut, starting with the front face and then the ends and diaphragms.

8. Illustrations of gabion installations are shown in figures B.9.7, B.9.8, and B.9.9.

RESOURCE COMMITMENT = 4:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 2:	5	4	3	2	1
	High		Medium		Low

PRECAUTIONS

Care should be exercised that the gabions are constructed on a firm soil base or are otherwise not stacked so high that overturning is likely.

REFERENCES

1. *Instructions for Assembly and Erection,* Maccaferri Gabions, Williamsport, MD, August 1988.

2. *Procedures and Standards for Bridge Maintenance*, Report FHWA-PA-89-39+86-08, Pennsylvania Department of Transportation, June 1990.

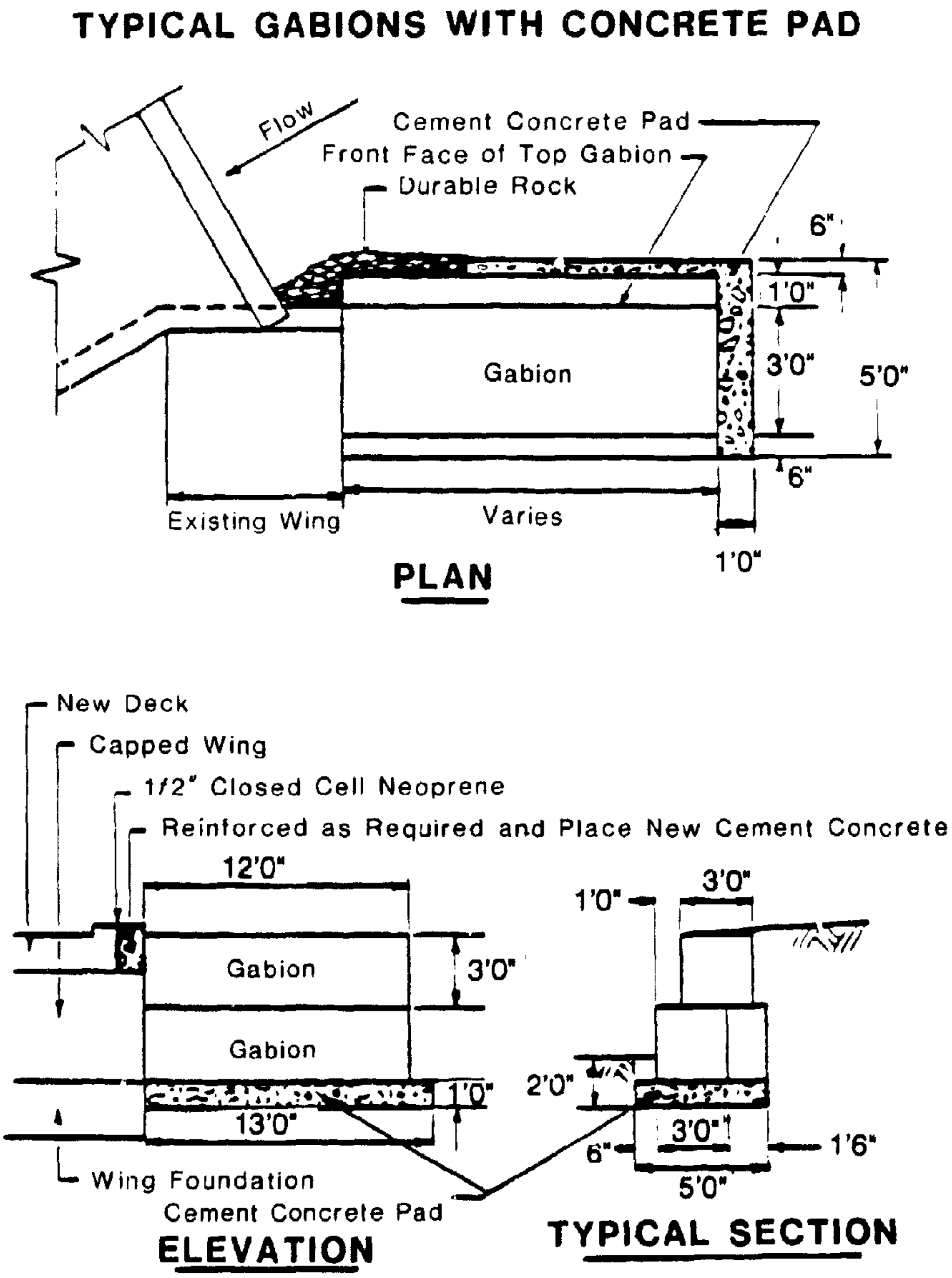


Figure B.9.7. Gabion Wingwall.(2)

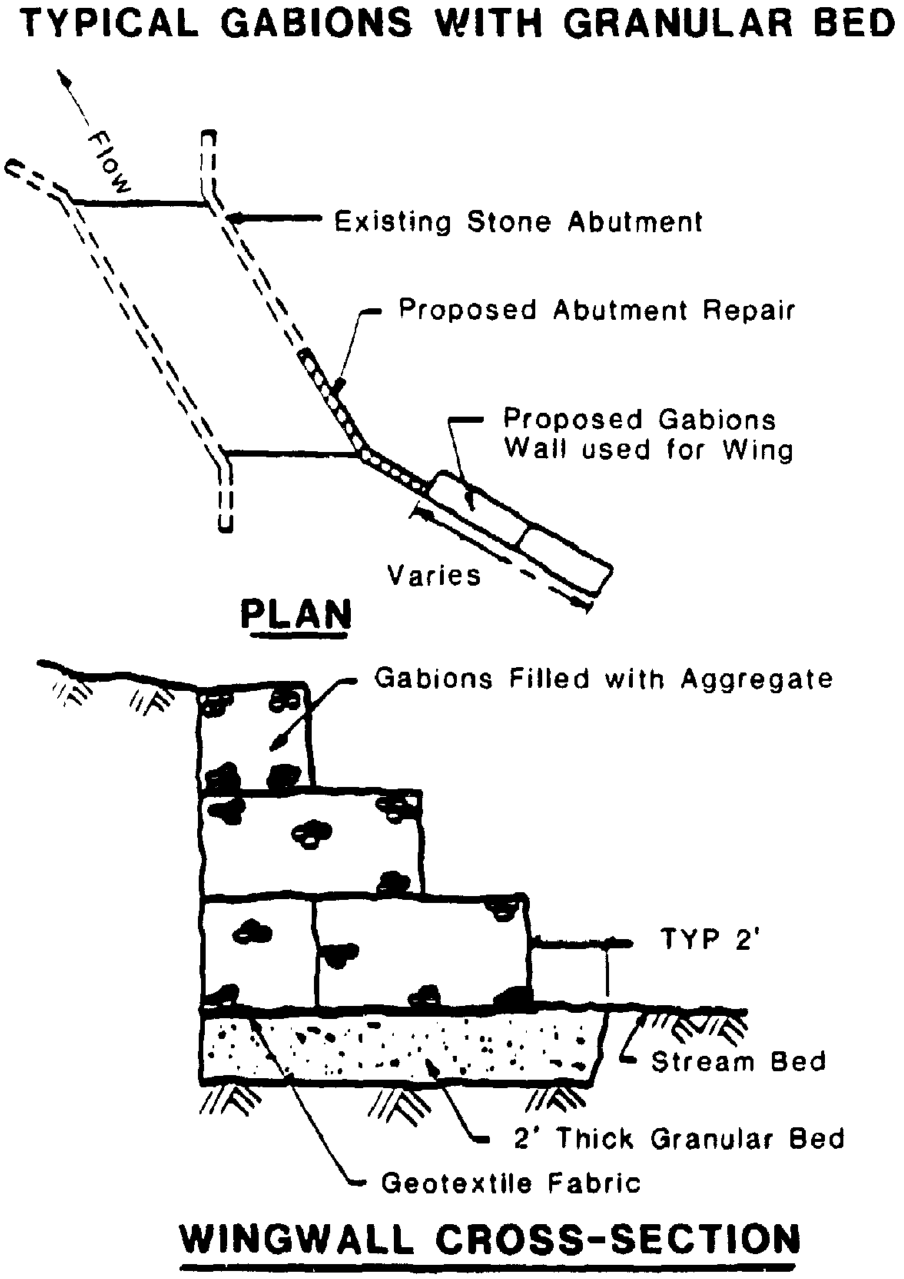
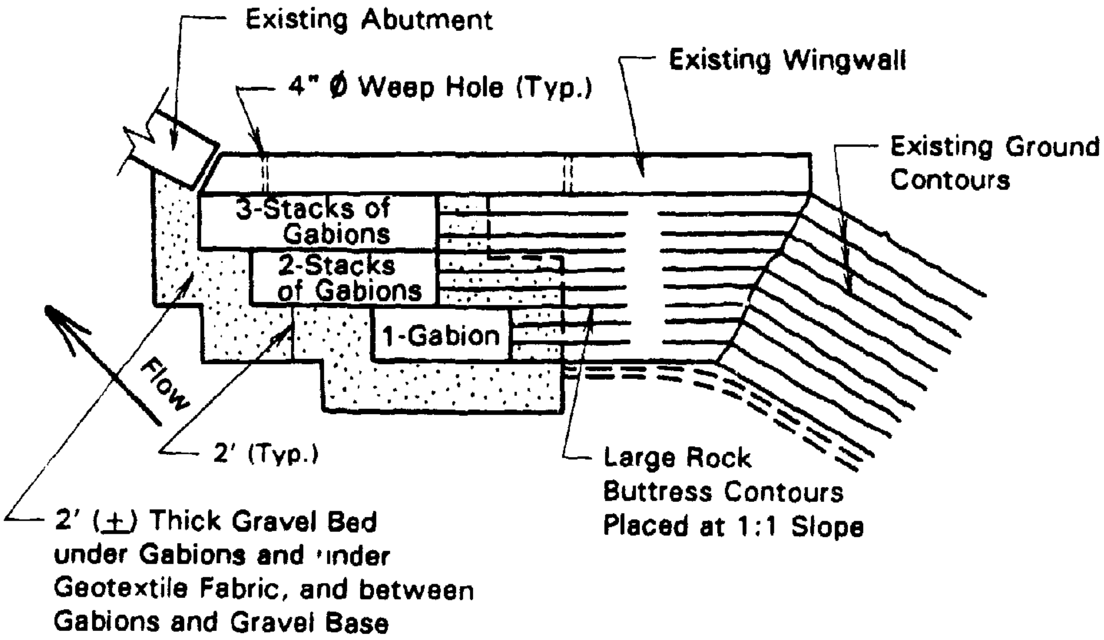
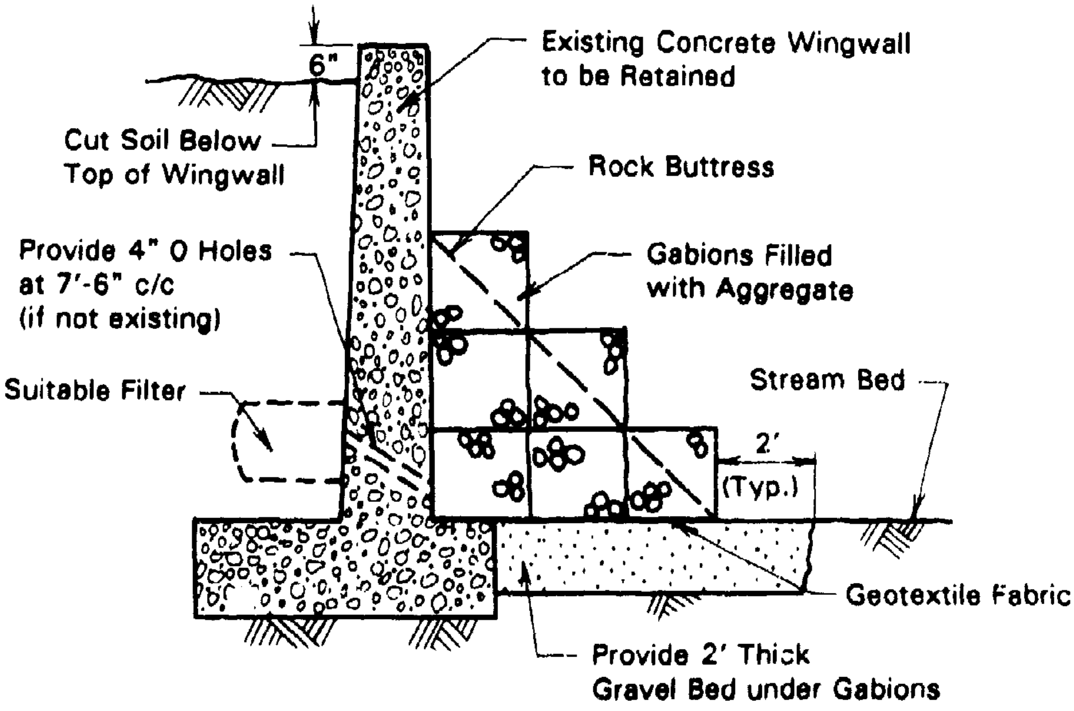


Figure B.9.8. Use of gabions to extend wingwalls.[2]



PLAN



WINGWALL CROSS-SECTION

Figure B.9.9. Stabilization of wingwall with gabions.(2)

APPENDIX B-10. PROCEDURES FOR REPAIR OF TIMBER STRUCTURES

APPLICATIONS

The procedures described below apply to the repair of both timber culverts and timber retaining walls.

COMMENTS

Douglas fir and southern long leaf yellow pine are the most common species used in heavy timber construction. These same types of timber should be used for repair of timber structures. When treated Douglas fir is to be used, coastal Douglas fir should be specified since it accepts preservative treatment better than inland varieties.

Three materials are commonly used to protect timber and all are applied under pressure. The three are creosote, pentachlorophenol, and copper chromium arsenate (CCA). The empty cell process is generally specified since it leaves a preservative coating on the internal surface of the cells, but it does not leave a heavy residue of preservative on the outer surface of the timber. This fact is significant because all of the materials used for preservative treatment are toxic.

Galvanized hardware should be used for repair of all permanent structures. Ordinary hardware can be used for temporary structures such as scaffolding, however.

PROCEDURES

1. Repairing Damage From Rot

   a. Determine the extent of the damage or deterioration. This is usually done by sounding in the case of rot.

   b. Determine whether temporary supports will be required when damaged or deteriorated wood is removed.

   c. When repairing timber damaged by rot, determine whether or not to replace the entire piece of timber or remove only the rotten portion.

   d. When it is not reasonable to replace the entire member, all timber showing visible signs of decay should be removed plus two additional feet in the direction of the grain.

   e. Install a splice between the existing timber and the new timber.

   f. Remove all sawdust and chips from the work site.

g. Since the presence of unnecessary moisture is the most common root cause of timber decay, eliminate moisture-retaining debris from all timber surfaces.

2. Repairing Damage by Overload

   a. When timber has been damaged by overload rather than rot, repair can be made by adding a sister member, which is a new member added adjacent to the similar existing one.

   b. Since the presence of rot-causing fungi is not always visible on damaged timber, the sister member usually should be isolated from the existing member by heavy roofing or similar material.

3. General

   a. The installation of sheet metal caps to help control deterioration on timber ends has been a common practice. In most cases, however, this practice accelerates deterioration instead of reducing it by acting as a funnel directing water into the timber and retaining moisture. Consequently, the use of such caps should be avoided.

   b. A minimum number of cuts and holes should be made in treated timber. The cuts and holes that have to be made should be thoroughly swabbed with protective material. Pentachlorophenol is a convenient material to use for this purpose.

   c. Timber is strong in both tension and compression but is relatively weak in horizontal shear. As a result, satisfactory connections between members carrying heavy loads can be difficult to obtain where the loads must be transferred by hardware rather than by direct timber-to-timber contact. In these instances the use of shear transfer devices, such as a split ring connector, should be used.

SAFETY PRECAUTIONS

All of the materials used for preservative treatment are toxic. Therefore, appropriate gloves and other suitable protective items should always be worn when handling treated timber.

RESOURCE COMMITMENT = 1:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. M.C. Rissel, and J.P. Taylor, *Procedures and Standards for Bridge Maintenance*, Research Project 86-08. Pennsylvania Department of Transportation, Harrisburg, PA, June 1990.

APPENDIX B-11: PROCEDURES FOR SHOTCRETE/GUNITE PAVING, LINING, AND REPAIRS

APPLICATIONS

Shotcrete may be used for the following types of work:

- Repairing damaged and/or deteriorated headwalls, endwalls, and wingwalls of culverts;
- Repairing and/or paving culvert inverts;
- Retrofitting inlet and outlet features to provide increased flow capacity, to inhibit abrasion damage, and to facilitate fish passage;
- Lining approach channels; and
- Lining corrugated metal culverts to increase flow capacity by reducing roughness of the inside surface.

COMMENTS

The terms "shotcrete" and "gunite" refer to the process of pneumatically transporting and placing Portland cement-based mortar or concrete with compressed air. Although the term shotcrete may generally be used for all related processes, the term gunite frequently refers to a dry mix, whereas shotcrete may refer to both wet and dry mixes. As with conventional Portland cement concrete, the physical properties of wet and dry shotcrete mixes depends upon many factors, including the relative amounts of water, cement, and chemical admixtures, as well as the maximum size of the aggregate that is used.

Shotcrete has advantages over conventional concrete for many types of repair work. It is especially advantageous where formwork is impractical or where forms can be reduced or eliminated, where access to the work area is difficult, and where thin or variable thicknesses are necessary. Properly applied shotcrete is structurally sound and durable. It has excellent bonding characteristics with concrete, masonry, rock, and steel. However, these properties are very dependent upon the use of good materials and procedures by a knowledgeable and experienced nozzleman to adjust the amount of water added to the mix. Figures B.11.1 through B.11.5 illustrate the proper shooting positions and procedures to produce the best shotcrete.

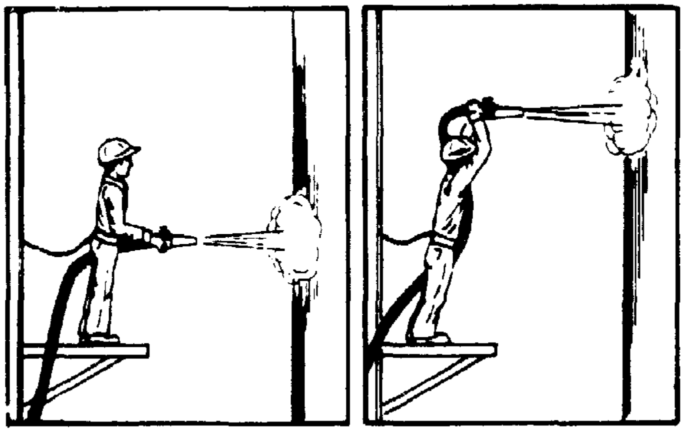


Figure B.11.1. Correct shooting positions.(1)

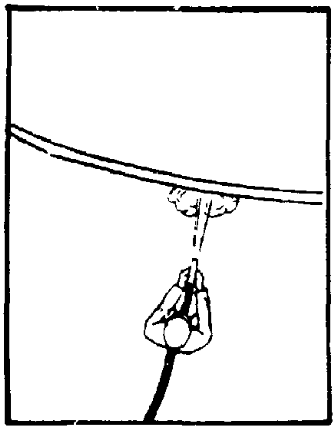


Figure B.11.2. Square or radial to wall.(1)

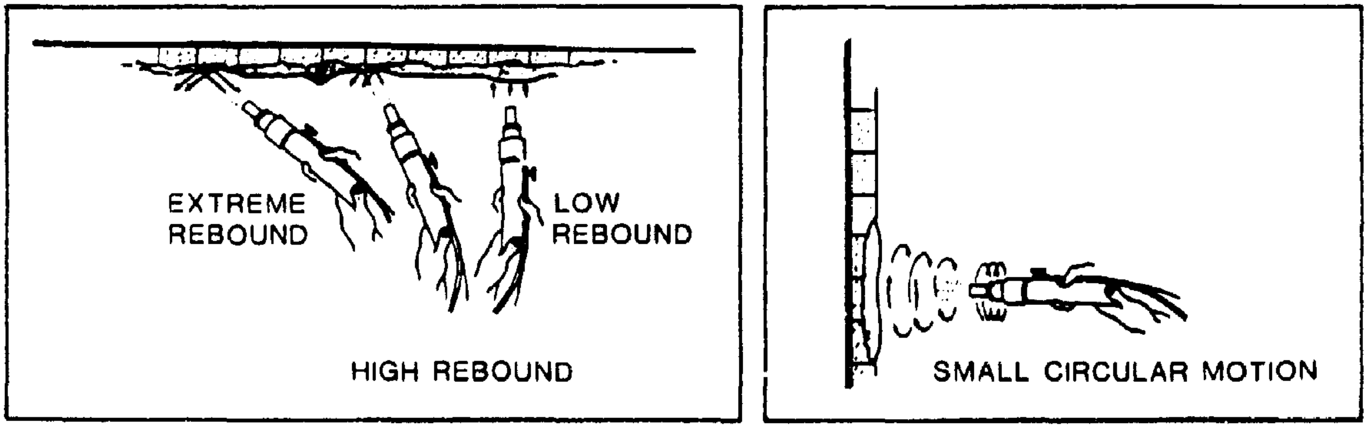


Figure B.11.3. Manipulating the nozzel to produce the best shotcrete.(1)

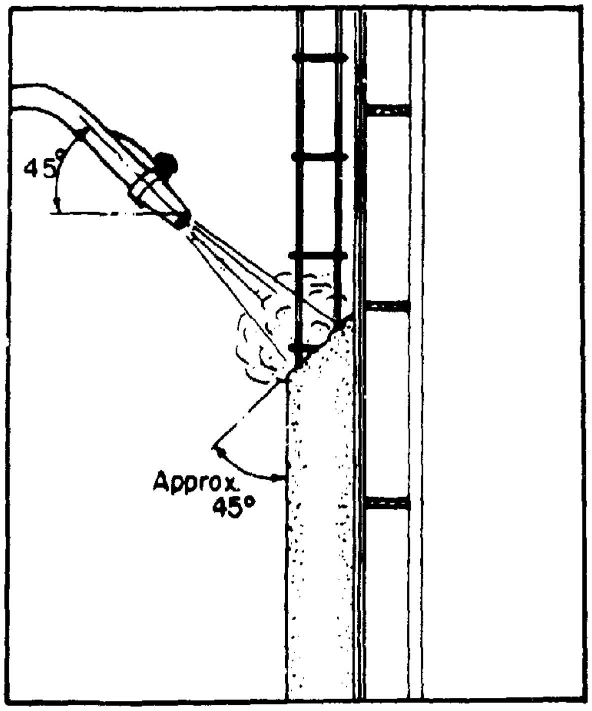


Figure B.11.4. Correct shooting for thick applications.(1)

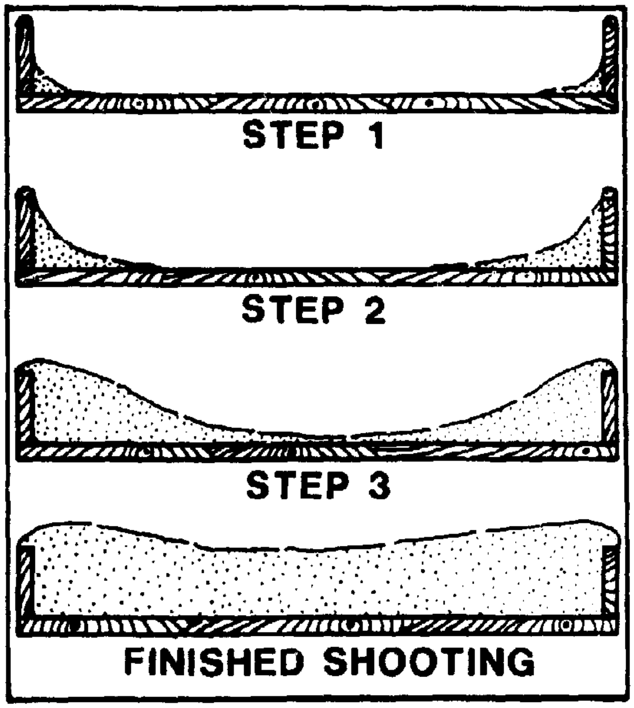


Figure B.11.5. Proper procedure for gunning corners.(1)

It should be noted that a variety of Portland cement based materials may be pneumatically applied. The choice of materials will depend upon site-specific conditions and requirements for the materials. Typical materials include conventional concrete, high strength concrete and steel fiber reinforced concrete. Information on these materials is available in the cited references.

PROCEDURES

1. It is essential that the work area be properly prepared for the application of both dry and wet shotcrete mixes. Steel surfaces should be cleaned of loose mill scale, rust, oil, paint, or other contaminants. 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.

2. Steel reinforcement, consisting of welded wire mesh fabric or plain or deformed reinforcing bars, is required for installations where shotcrete must carry structural loads or drying shrinkage cracking must be avoided. The amount, size, and distribution of reinforcing steel should be determined as for conventional reinforced structures. The reinforcement should be rigidly secured in position with anchorage devices to assure structural interaction of the shotcrete with the existing structure. Figure B.11.6 illustrates the proper method of encasing reinforcing bars.

3. Earth, concrete, and masonry surfaces should be predampened so as to minimize absorption of water from the shotcrete and the creation of a weak interface bond; however, the surface should be free of standing water.

4. The shotcrete should be mixed, pneumatically transported, and placed in accordance with recommendations and guidelines contained in documents of the American Concrete Institute (ACI) and/or the shotcrete industry.

5. Immediately after finishing, shotcrete should be kept continuously moist for at least 24 hours by using (a) ponding or sprinkling, (b) an absorptive mat, fabric, or other covering, or (c) a curing compound.

SAFETY PRECAUTIONS

The potential of problems and injury due to construction with shotcrete 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 skin and eye damage.

NOZZLE DIRECTION AND FLIGHT OF MATERIAL

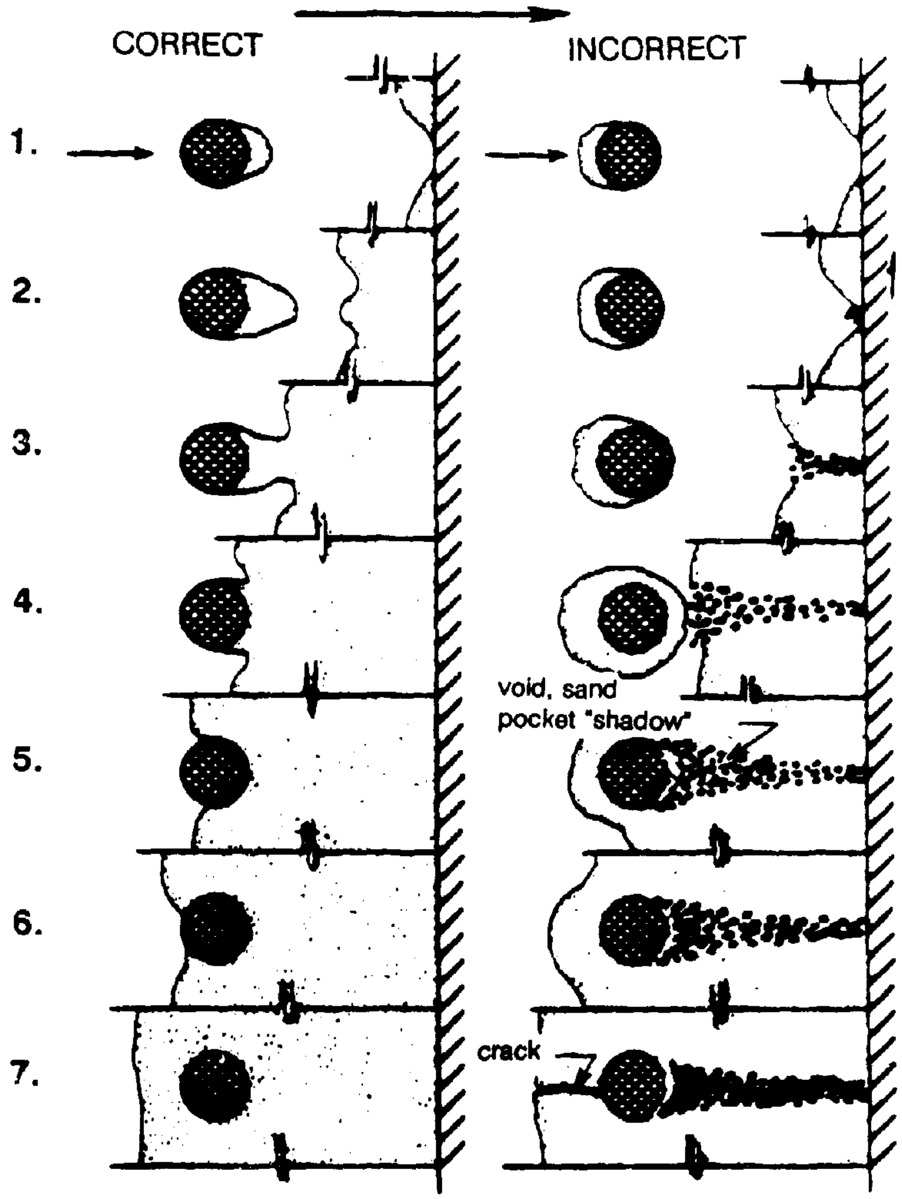


Figure B.11.6. Correct and incorrect method of encasing reinforcing bars.(1)

RESOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 2:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. "Guide to Shotcrete." (ACI 506R-90), *ACI Manual of Concrete Practice*, American Concrete Institute, 1990.

2. "Specification for Materials, Proportioning, and Application of Shotcrete," (ACI 506.2-77), *ACI Manual of Concrete Practice*, American Concrete Institute, Revised 1983.

3. "State-of-the-Art Report on Fiber Reinforced Shotcrete," (ACI 506.1R-84), *ACI Manual of Concrete Practice*, American Concrete Institute, 1984.

4. "Guide to Certification of Shotcrete Nozzlemen." ACI *Manual of Concrete Practice*, American Concrete Institute, 1982.

5. "Rehabilitation of Corrugated Steel Pipe and Pipe Lines of Other Materials." *Drainage Technology Bulletin*, National Steel Pipe Institute, September 1988.

APPENDIX B-12. PROCEDURES FOR STORMWATER CONVEYANCE CHANNELS (DITCHES)

APPLICATIONS

This section is generally applicable to man-made channels, including roadside ditches and paved flumes, and intermittent natural channels that are modified to accommodate increased flows generated by stormwater runoff. This practice is not applicable to major, continuous flowing natural streams.

COMMENTS

A stormwater conveyance channel is a permanent, designed waterway, shaped and lined with the appropriate vegetation or structural material to safely convey excess stormwater runoff. The purpose of such a channel is to provide for the disposal of concentrated surface runoff water without damage from erosion.

The design of a channel cross-section and lining is based primarily upon the volume and velocity of flow expected in the channel. If conditions are appropriate, grass or riprap channels are generally preferred over concrete. While concrete channels are efficient and easy to maintain, they remove water so quickly that channel erosion and flooding may result downstream. Grass or riprap channels reduce this problem by more nearly duplicating a natural system.

Other factors such as land availability, compatibility with land use and the surrounding environment, maintenance requirements, and outlet conditions must also be considered when selecting a cross-section and lining. Cross-sections may be one of the following:

Vee-Shaped ditches are generally used where the quantity of water is relatively small, such as along roadways. A grass or sod lining is sufficient where velocities are low. For steeper slopes, a concrete or bituminous lining may be appropriate. A vee-shaped ditch is more erosion prone than parabolic or trapezoidal-shaped ditches. It is, therefore, only recommended for small discharges on mild slopes.

Parabolic channels are often used where the quantity of water to be handled is greater and where space is available for a wide, shallow channel with low velocity flow. Riprap should be used where high velocities are expected. A combination of grass and riprap is useful where there is continuous low flow in a channel.

Trapezoidal channels are often used where the quantity of water to be handled is large and conditions require that it be carried at a relatively high velocity. Trapezoidal ditches are generally lined with concrete or riprap.

Outlet conditions for all channels should be considered, particularly at the transition from a man-made lining such as concrete to a vegetative lining. Appropriate measures must be taken to dissipate the energy of flow to prevent scour of the receiving channel.

PROCEDURES

Capacity

Unless otherwise specified by local and State drainage criteria, design channel capacity and erosion protection for a 2-year frequency storm. If property damage from channel flooding is problematic, design capacity for a 10-year frequency storm.

Velocity

Design channels so that the velocity of flow expected from a 2-year frequency storm does not exceed the permissible velocity for the type of lining used.

Grass-lined channels - Permissible velocities for grass-lined channels is shown in table B.12.1 below. However, local specifications should be used for selecting the appropriate grass for the area.

Riprap-lined channels - Riprap linings can be designed to withstand most flow velocities by choosing a stable stone size. The procedure for selecting a stable stone size can be found in appendix B, section B.13, Riprap.

Concrete-lined channel - Velocity is usually not a limiting factor in the design of concrete-lined channels. However, flow velocity at the outlet of the paved section must not exceed the permissible velocity of the receiving channel.

Cross Section

Channel cross-sections may be vee-shaped, parabolic, or trapezoidal. The top width of parabolic and vee-shaped, grass-lined channels should not exceed 30 feet. The bottom width of trapezoidal, grass-lined channels should not exceed 15 feet unless multiple or divided waterways, a riprap center or other means are provided to control meandering of low flows.

Channel linings

Grass - The type of grass chosen must be appropriate for site conditions. It must comply with requirements such as allowable flow, shade tolerance, and maintenance needs. The method used

Table B.12.1. Permissible velocities for grass-lined channel.(1)

Channel Slope	Lining	Permissible Velocity
0.5%	Bermuda grass	6 ft/sec
	Tall Fescue	5 ft/sec
	Kentucky blue grass	
	Grass-legume mixture	4 ft/sec
	Red fescue	2.5 ft/sec
	Redtop	
	Sericea lespedeza	
	Annual lespedeza	
	Small grains (temporary	
5-10%	Bermuda grass	5 ft/sec
	Reed canary grass	4 ft/sec
	Tall fescue	
	Kentucky blue grass	
	Grass-legume mixture	3 ft/sec
Greater than 10%	Bermuda grass	4 ft/sec
	Reed canary grass	3 ft/sec
	Tall fescue	
	Kentucky blue grass	

[a] For highly erodible soils, permissible velocities should be decreased 25%.

to establish grass in the ditch or channel generally depends upon the slope, allowable velocity, the erosion-resistance of the soils, and whether or not the majority of the drainage can be diverted away from the channel during germination to permit growth and establishment. Some methods available for grass establishment are:

- Seeding with straw mulch and tack coat.
- Sprigging with Bermuda grass.
- Sodding.
- Geotextiles: Polymer erosion control mat linings that are three-dimensional systems used to establish a reinforced system used to establish a reinforced vegetative surface. Additional information can be found in appendix B, section 7: Geotextiles, Turf Reinforcement.
- Erosion control blankets such as those made from wood excelsior combined with a photo-degradable plastic mesh. High-velocity erosion control blankets are also available.

<u>Riprap-lined channels</u> - Riprap should be installed in accordance with appendix B, section 13, Riprap, or as specified by local or state regulations.

<u>Concrete-lined channels</u> - Concrete-lined channels should be at least 4 inches thick and meet applicable local and state criteria.

<u>Shotcrete-lined channels</u> - Shotcrete is particularly cost effective where formwork is impractical or where forms can be reduced or eliminated, access to work is difficult or thin layers of variable thicknesses are required. The physical properties of sound shotcrete are comparable or superior to conventional concrete having the same composition.

<u>Patented erosion control systems</u> used to line channels. An example of this type of lining is TRI-LOCK(2), a flexible, permeable erosion control system of precast concrete blocks made up of two components, a "lock block" and a "key block," installed over a specially designed plastic filter fabric. This system is normally installed in dry conditions by hand placing on the overlying filter fabric. For underwater applications, it can also be supplied on pre-assembled mats.

SAFETY PRECAUTIONS

Safety precautions related to the placement of Shotcrete should be observed. These problems are outlined in Appendix B, Section 11: Procedures for Shotcrete/Gunite Paving, Lining, and Repairs[3].

RESOURCE COMMITMENT = 4:	5	4	3	2	1
	Heavy		Medium		Low

COST RELATIVE TO REPLACEMENT = 2:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. *Virginia Erosion and Sediment Control Handbook*, Second Edition. Virginia Department of Conservation and Historic Resources, Division of Soil and Water Conservation, Richmond, VA, 1980.

2. *TRI-LOCK Erosion Control System Specifications*," American Excelsior Company, Arlington, TX.

3. "Guide to Shotcrete." (ACI 506R-90), *ACI Manual of Concrete Practice*, American Concrete Institute, 1990.

APPENDIX B-13. PROCEDURES FOR INSTALLING RIPRAP

APPLICATIONS

Riprap can be installed on soil-water interfaces where the soil conditions, water turbulence and velocity, or expected vegetative cover are such that the soil may erode under design flow conditions. Riprap may be used, as appropriate, at stormdrain outlets, on channel banks or bottoms, around culvert appurtenances to prevent erosion and scour, in roadside ditches, and along the toe of slopes. The purposes fulfilled by the placement of riprap are as follows:

- To protect the soil surface from the erosive forces of concentrated runoff;
- To slow the velocity of concentrated runoff while enhancing the potential for infiltration;
- To stabilize slopes with seepage problems and/or non-cohesive soils; and
- To stabilize streambeds and streambanks exposed to increased velocity and turbulence at culvert inlets and outlets.

COMMENTS

There are several types of riprap that are considered to be permanent flexible linings. These types are described as follows:

- Rock riprap - Rock riprap is dumped in place on a filter blanket or prepared slope to form a well-graded mass with a minimum of voids. Rocks should be hard, durable, preferably angular in shape, and free from overburden, shale, and organic material. It should be noted that hand-placed riprap is considered to be a rigid lining since it cannot accommodate even minor movement of the surface it protects.
- Gravel riprap - Gravel riprap consists of coarse gravel or crushed rock placed on filter blankets or on a prepared slope to form a well-graded mass with a minimum of voids. The material is composed of tough, durable, gravel-sized particles and should be free from organic matter.
- Wire-enclosed riprap - Wire-enclosed riprap, usually known as gabions, is manufactured from a rectangular container made of steel wire, woven in a uniform pattern and reinforced on the corners and edges with heavier wire. The containers are filled with stone, connected together, and anchored to the channel side slope. Stones must be well graded and durable. Wire-enclosed riprap is typically used when high quality rock

riprap is either not available or not large enough to be stable. Further information can be found in appendix B, section 9, Gabions.

Methods discussed below refer to dumped rock riprap only.

Riprap Design in Channels

A design method for riprap in channels is included in appendix C, entitled "Riprap Design in Channels." The method is adopted from Hydraulic Engineering Circular No. 15[1] of the Federal Highway Administration and the simplified method included in the *Virginia Erosion and Sediment Control Handbook.*[2] However, local specification for riprap design should be followed.

Riprap used with erosion control geotextiles - To prevent the erosion of soil through the armoring layer of riprap, geotextiles are used between the soil and the riprap. The geotextile is used in lieu of a conventional graded aggregate filter. In this application, riprap is placed over the geotextile to protect the streambed and streambanks.

Two key criteria must be met for this application of geotextiles. First, the geotextile must have sufficient permeability to permit the passage of water, thus relieving hydrostatic pressure behind the armor layer. Second, the geotextile must be capable of retaining the soil particles under the armor. The specification for the geotextile is included in appendix C, and is entitled "Task Force 25 Specification Guide for Erosion Control Geotextiles."[3]

PROCEDURES

1. Riprap and Geotextile Placement for Streambank/Streambed Protection

   a. If a portion of the streambed is to be lined, construct a sandbag cofferdam to an elevation above the water level or divert the stream using temporary pipes.

   b. Install sediment control devices.

   c. Prepare foundation by removing unsuitable material, sediment, vegetation, and debris.

   d. Backfill with suitable material if required.

   e. Select appropriate geotextile as specified in "Task Force 25 Specification Guide for Erosion Control Geotextiles,"[3] included in appendix C.

   f. Place the geotextile as described in appendix B, section 7, Geotextiles: Part 2 - "Geotextiles Used with Riprap."

g. Place the geotextile so that it will not stretch or tear excessively.

h. Anchor the terminal ends by using the key trenches or aprons at the crest and toe of the slope as described in (f) above.

i. Overlap successive geotextile sheets in such a manner that the upstream sheet is placed over the downstream sheet and/or upslope over downslope. In underwater application, place the geotextile and riprap the same day. Begin the riprap placement at the toe and proceed up the slope.

j. Overlap seams a mini[illegible] 12 inches except when placed underwater where the overlap shal[illegible] minimum of three feet. Secure with anchor pins, 15 inches long, placed every three feet along the overlap.

k. Riprap and heavy stone filling should not be dropped onto the geotextile from a height to exceed one foot. Slope protection and smaller sizes of stone filling should not be dropped from a height exceeding three feet. For large stones (12 inches or greater), a 4-inch layer of gravel may be necessary to prevent damage to the cloth.

l. Placement of stones should follow immediately after placement of the filter. The riprap should be placed so that it produces a dense well-graded mass of stone with a minimum of voids. It should be placed to its full thickness in one operation, not in layers. The riprap should not be placed by dumping into chutes or similar methods that are likely to cause segregating of the stone sizes.

m. Remove sediment control devices.

2. Riprap and Geotextile Placement to Provide Scour Protection

NOTE: This construction to be done in the dry condition only.

a. Construct a sandbag cofferdam to an elevation above the water level or divert the stream using temporary pipes.

b. Install a sediment control device.

c. Probe the scour hole to determine its approximate size. Remove sediment, unsuitable material and debris from the scour hole.

d. Excavate the scour hole to a minimum of 3 feet wide and 3 feet deep to the natural streambed material.

e. Select the appropriate geotextile as specified in "Task Force 25 Specification Guide for Erosion Control Geotextiles,"[3] included in appendix C.

f. The geotextile should be placed as described in appendix B, section 7, Geotextiles: Part 2 - "Geotextile Used With Riprap," with the following exception. The geotextile should line the scour hole and be placed so that the fabric will overlap a minimum of 3 feet downstream as shown below:

g. Placement of fabric and riprap should follow the process outlined in 1(i) through 1(m) in the preceding procedure.

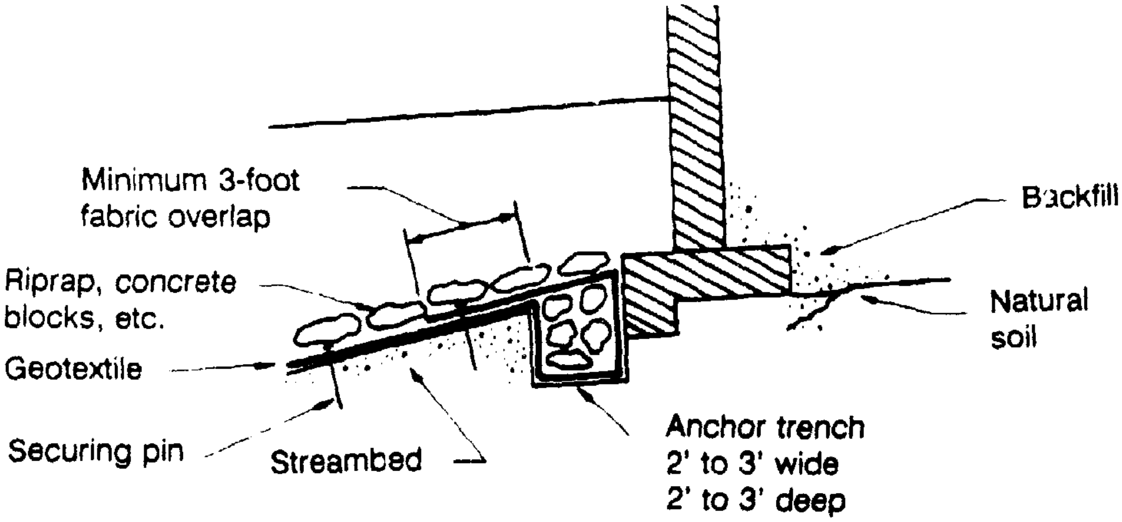


Figure B.13.1 Use of geotextiles to prevent scour. Adapted.[3]

SAFETY PRECAUTIONS

1. Riprap for slope stabilization must be designed so that the angle of repose of the stone mixture is greater than the gradient of the slope being stabilized.

2. Finished riprap should be free of pockets of small stones or clusters of large stones. Minimum hand placing may be necessary to achieve the required grades and a good distribution of stone sizes. However, excessive hand placement will result in a rigid lining that will be less resilient when movement occurs.

3. Care should be taken by workmen probing the stream for depth of scour because of the current and unknown depth of the hole.

RESOURCE COMMITMENT = 2:	5 Heavy	4	3 Medium	2	1 Low
COST RELATIVE TO REPLACEMENT = 2:	5 High	4	3 Medium	2	1 Low

REFERENCES

1. *Design of Roadside Channels with Flexible Linings*, Hydraulic Engineering Circular No. 15, FHWA-IP-87-7. US Department of Transportation, Federal Highway Administration, McLean, Virginia, April 1988.

2. *Virginia Erosion and Sediment Control Handbook*, Virginia Department of Conservation and Historic Resources, Division of Soil and Water Conservation, Richmond, Virginia, 1980.

3. *Task Force 25 Specification Guides, TS25*, Joint Committee on New Highway Materials, AASHTO, Washington, DC, 1989.

APPENDIX B-14. PROCEDURE FOR REPAIR AND REPLACEMENT OF APRON/CUTOFF WALL

APPLICATIONS

This procedure is applicable to the repair and replacement of all or portions of existing culvert concrete or masonry aprons and cutoff walls.

COMMENTS

Aprons and cutoff walls help to protect the slopes and channel bed from scour. Undermining is one of the major causes of failure of the aprons. If caught early, voids below can be filled and cutoff walls added as necessary to prevent further undermining. Care should be exercised to maintain the flow of water over aprons so as not to restrict fish passage.

PROCEDURES

1. Install sediment control devices.

2. Construct sluices or other devices to divert stream and to protect freshly placed concrete from flowing water.

3. Remove deteriorated masonry or concrete.

4. Excavate unsuitable material. The apron should not protrude above the normal streambed elevation.

5. Place and compact base material.

6. Drill holes and set dowels with non-shrink grout or approved adhesive.

7. Construct formwork. Aprons should extend at least one pipe diameter upstream.

8. Place reinforcing steel.

9. Place concrete. Just prior to placing concrete, apply epoxy bonding agent to all existing concrete that is to come into contact with new concrete.

10. Remove formwork.

11. Remove sluices and sediment control devices.

12. Grade streambed.

RESOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 2:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. Martin C. Rissel, John P. Taylor,and Robert J. Vollmer, *Procedures and Standards for Bridge Maintenance*, Final Report, Research Project 86-08, Pennsylvania Department of Transportation, June 1990.

APPENDIX B-15. PROCEDURES FOR STREAMBED PAVING

APPLICATIONS

The following procedure applies to the paving or repair of paving in streambeds adjacent to highway culverts.

COMMENTS

Although streambed paving is not desirable, it is occasionally necessary as a permanent solution to a longstanding problem of erosion or to provide capacity where space for a larger ditch is limited. This is particularly true when more traditional forms of erosion control, such as riprap, gabions, or various types of energy dissipators, are not effective. Streambed paving may be essential to protect the footings of arch culverts.

The scheduling of this type of work should be based on need, as indicated by inspections and/or changes in stream flow or conditions that increase the potential for scour problems. The work can be most efficiently performed during periods of low water, which are most likely to occur during late summer or early fall.

PROCEDURES

Paving or repair of paved streambeds should be performed in accordance with plans, specifications, and procedures that are established for each specific project. The work area includes the entire width and breadth of existing streambed areas or areas indicated on the plans for new streambed paving. In addition, sufficient additional space is needed to allow for required excavation and for the construction of sluices or other means to conduct water through the structure and to protect the work area and freshly placed concrete from flowing water during the paving operation.

When protective material, such as riprap, is excavated to gain access to the work, it should be replaced in conformance with existing standards and procedures or procedures established for this specific project.

The work procedure shall include, but is not limited to, the following:

1. Install sediment control devices.

2. Excavate unsuitable material and dispose of properly.

3. Backfill with suitable material.

4. Place and compact base material.

5. Drill holes and install dowels.

6. Erect formwork.
7. Place reinforcing steel.
8. Place Class A concrete 6" thick to dimensions shown on plans.
9. Saw 3/16" x 2" joints as soon as practical after placement.
10. Tool edges to 1/4" radius.
11. Place preformed joint filler.
12. Remove sediment control devices.

PRECAUTIONS

Special precautions and permits may be required for general construction in streams that are inhabited or used by fish and wildlife, particularly with regard to:

Placement of Portland cement concrete
Sedimentation and/or erosion of soils

RESOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 2:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. Richard E. Weyers and Richard M. McClure, *A Collection of Attempted Maintenance Force Remedial Bridge Work*, Report FHWA/AP-84/003, Pennsylvania Department of Transportation, September 1983.

APPENDIX B-16. PROCEDURE FOR REPLACEMENT OF CONCRETE WINGWALLS AND ENDWALLS

APPLICATIONS

The procedure provided below can be used to replace wingwalls that have severely deteriorated or collapsed due to lateral pressure or undermining.

COMMENTS

This procedure should be used only if the endwall to which the wingwalls will be connected is sound. The work is to be performed in the dry. Design and materials should meet agency specifications.

PROCEDURES

1. If appropriate, notify waterway patrolman before working in stream.
2. Construct a sandbag cofferdam to an elevation above the water level or divert stream using temporary pipes.
3. Provide measures to minimize erosion and sedimentation to protect aquatic habitat.
4. Remove existing wing walls and excavate to sound material. Provide sheeting if necessary to contain fill.
5. Clean all concrete that is to come in contact with new concrete. Existing concrete shall be chipped and blast-cleaned to remove any unsound material and laitance.
6. Drill and set dowels.
7. Set forms and reinforcing steel and place concrete. Just prior to placing concrete, apply epoxy bonding compound to existing cleaned concrete that is to come in contact with fresh new concrete.
8. Prior to placing concrete, provide means for adequately reinforced weep holes.
9. Backfill adequately cured concrete wingwalls. Suitable filter shall be provided for weep holes.
10. Clean, grade, and seed work site. The area shall be in a presentable condition throughout.
11. Provide scour protection.

RESOURCE COMMITMENT = 3:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 3 :	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. Martin C. Rissel, John P. Taylor, and Robert J. Vollmer, *Procedures and Standards for Bridge Maintenance*, Final Report, Research Project 86-08. Pennsylvania Department of Transportation, June 1990.

APPENDIX B-17. PROCEDURE FOR REPAIR OF BASICALLY SOUND ENDWALLS AND WINGWALLS

APPLICATIONS

The information provided below can be used to repair wingwalls that are basically sound except for a deteriorated or broken section. The deterioration of the concrete should be related to factors other than the lack of air or bad aggregate. The wingwall should be in an upright position, not tipped.

COMMENTS

Materials used for replacing concrete wingwalls should conform to the requirements of the agency. Air entraining agents should always be used unless specifically omitted by special instructions. Calcium chloride should never be added to reinforced concrete as the chlorides contained in it accelerate the corrosion of the reinforcing steel.

The forms must be constructed true to line and grade and properly tied and braced. Before placing the concrete, the area where it is to be placed must be clean, the reinforcing bars properly tied, and the forms either wet with water or coated with an approved form-release agent.

PROCEDURES

1. Excavate as required to set dowels and forms.

2. Remove all fractured or deteriorated concrete to sound concrete by chipping, and blast clean to remove laitance.

3. Drill and set form anchor bolts and dowels. Dowels, #4 bars, are to be placed a minimum of 9 inches into sound concrete and set with non-shrink grout, 18 inches on center, front and back, as shown in figure B.17.1.

4. Cross-lace #4 bars as shown and set forms.

5. Just prior to placing concrete, apply epoxy bonding agent to all existing concrete that is to come into contact with new concrete.

6. Cure concrete for a minimum of 7 days before backfilling with granular material, or until concrete has developed sufficient strength to resist the imposed lateral pressures.

7. Backfill and provide erosion protection as necessary.

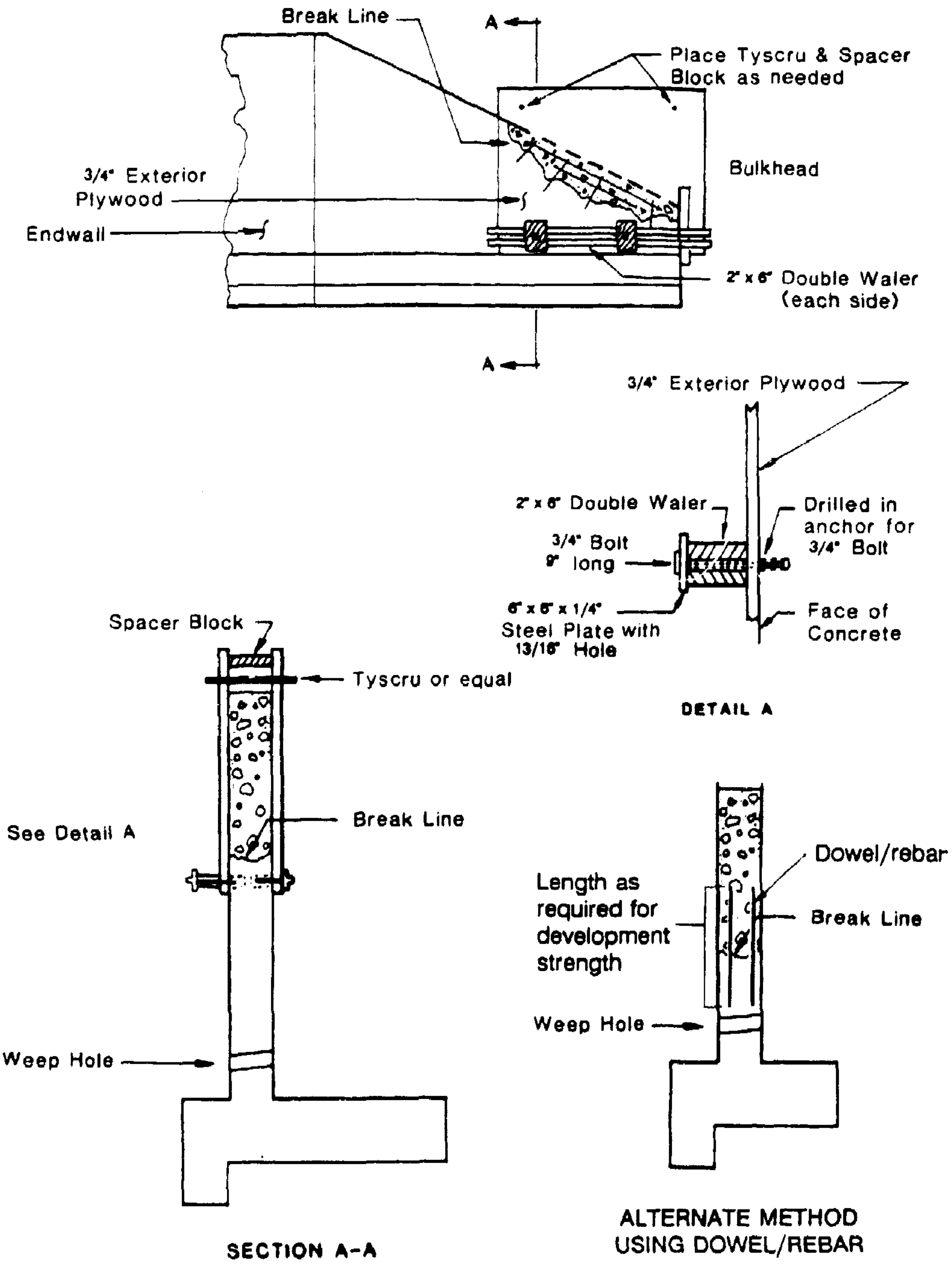


Figure B.17.1. Repair of basically sound wingwall.

RESOURCE COMMITMENT = 2:	5 Heavy	4	3 Medium	2	1 Low
COST RELATIVE TO REPLACEMENT = 2:	5 High	4	3 Medium	2	1 Low

REFERENCES

1. Martin C. Rissel, John P. Taylor, and Robert J. Vollmer, *Procedures and Standards for Bridge Maintenance*, Final Report, Research Project 86-08. Pennsylvania Department of Transportation, June 1990.

APPENDIX B-18. PROCEDURE FOR REPAIRING SEVERELY DETERIORATED OR COLLAPSED WINGWALLS AND ENDWALLS

APPLICATIONS

This procedure can be used to repair wingwalls and endwalls that are severely deteriorated or collapsed due to lateral pressure or undermining.

COMMENTS

Agency specifications for materials and placement of concrete should be followed.

PROCEDURES

1. If appropriate, notify waterway patrolman before working in stream.

2. Provide measures to minimize erosion and sedimentation to protect aquatic habitat.

3. Clean all concrete that is to come in contact with new concrete. Existing concrete shall be chipped and blast cleaned to remove any unsound material and laitance.

4. Drill and set dowels.

5. Set forms and reinforcing steel and place concrete. Just prior to placing concrete, apply epoxy bonding compound to existing cleaned concrete that to come in contact with fresh new concrete.

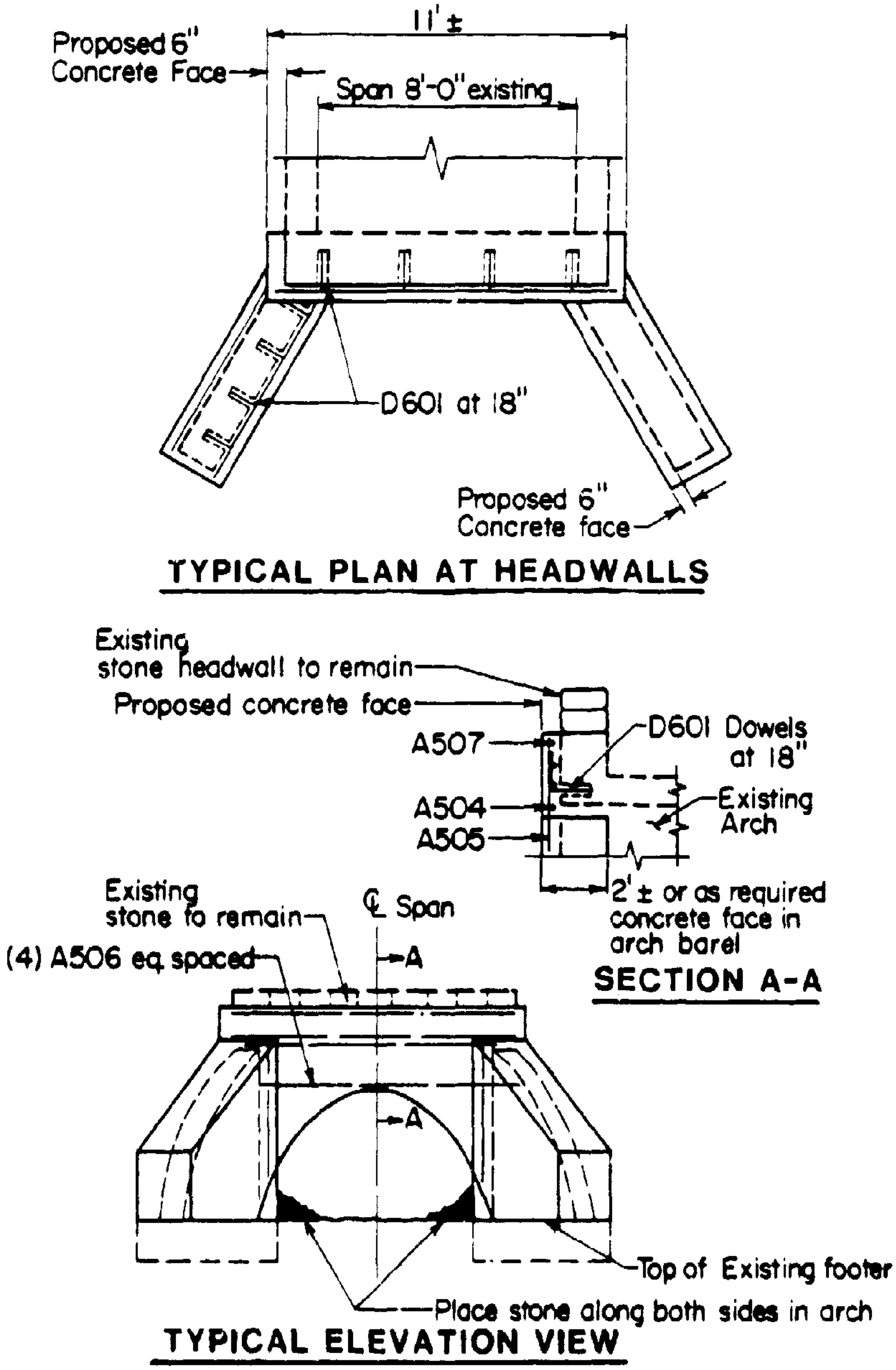
6. Prior to placing concrete, provide means for adequately reinforced weep holes.

7. Backfill adequately cured concrete wingwalls. Suitable filter shall be provided for weep holes.

8. Clean, grade, and seed work site. The area shall be in a presentable condition throughout.

9. Provide scour protection.

RESOURCE COMMITMENT = 3:	5 Heavy	4	3 Medium	2	1 Low
COST RELATIVE TO REPLACEMENT = 3:	5 High	4	3 Medium	2	1 Low

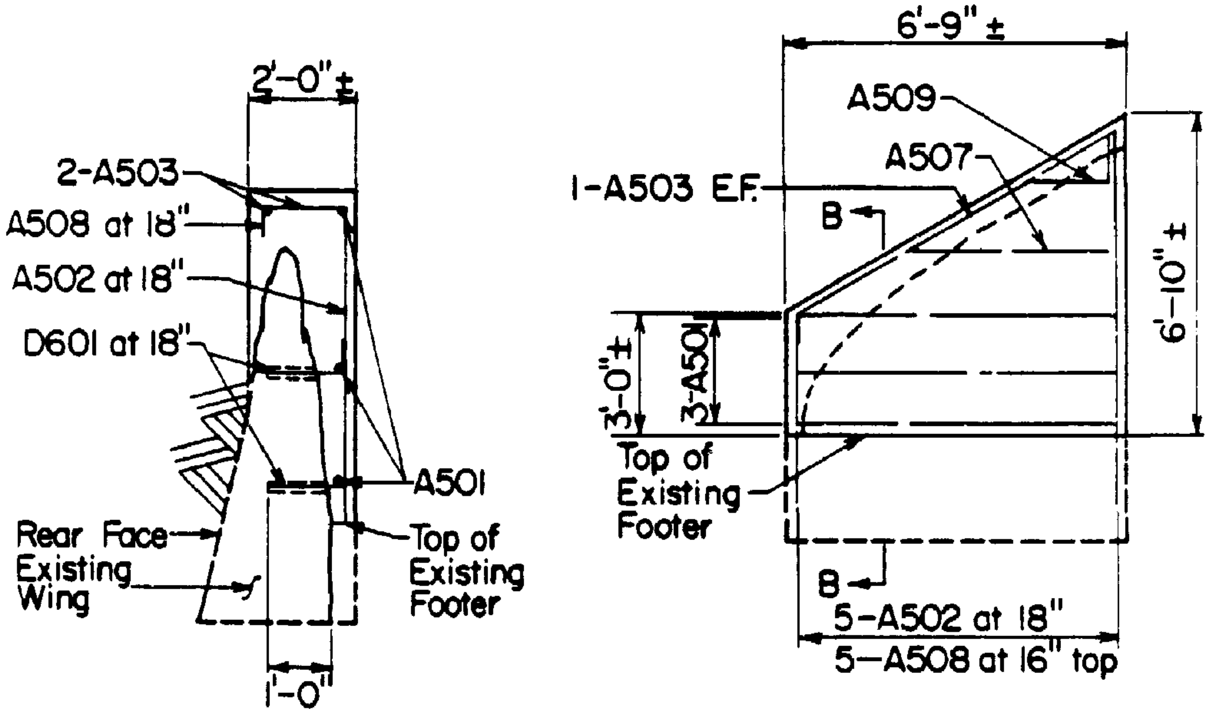


TYPICAL PLAN AT HEADWALLS

SECTION A-A

TYPICAL ELEVATION VIEW

Figure B.18.1. Repair of wingwalls.



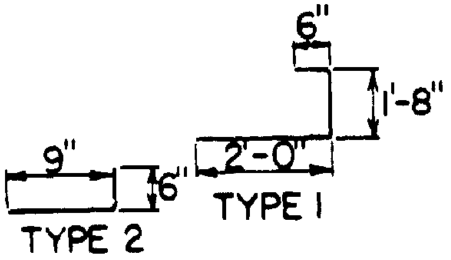
SECTION B-B

TYPICAL WING CAP

Figure B.18.2. Typical wing cap.

Table B.18.1. Reinforcement bars.

Mark	Size	No.	Length	Type	Remarks
A501	5	12	6'-5"	Str.	
A502	5	20	2'-9" to 6'-7"	Str.	4 each vary by 9 1/2"
A503	5	8	7'-0"	Str.	
A504	5	4	12'-0"	Bent	Bent in field
A505	5	16	2'-8" to 7'-8"	Str.	4 each vary by 1'-8"
A506	5	8	7'-8"	Str.	
A507	5	4	4'-0"	Str.	
A508	5	20	4'-2"	1	
D601	6	62	2'-3"	2	
A509	5	4	1'-6"	Str.	



REFERENCES

1. Richard E. Weyers and Richard M. McClure, *A Collection of Attempted Maintenance Force Remedial Bridge Work*, Final Report, Research Project 81-4. Pennsylvania Department of Transportation, Harrisburg, PA, September 1983.

APPENDIX B-19. PROCEDURE FOR CONCRETE JACKET REPAIRS FOR ENDWALLS AND WINGWALLS

APPLICATIONS

This procedure can be used to repair the deteriorated face of concrete endwalls or wingwalls when the deterioration of the concrete is not related to lack of air in the concrete, inferior to inadequate aggregate, or another progressive concrete deterioration problem.

COMMENTS

Agency specifications for materials and placement of concrete should be followed. Endwalls and wingwalls should be jacketed only when the existing material is deemed sound.

PROCEDURES

1. Remove deteriorated concrete and laitance by chipping and blast cleaning.

2. Drill and set tyscrus and lagstuds.

3. Set reinforcing steel and forms.

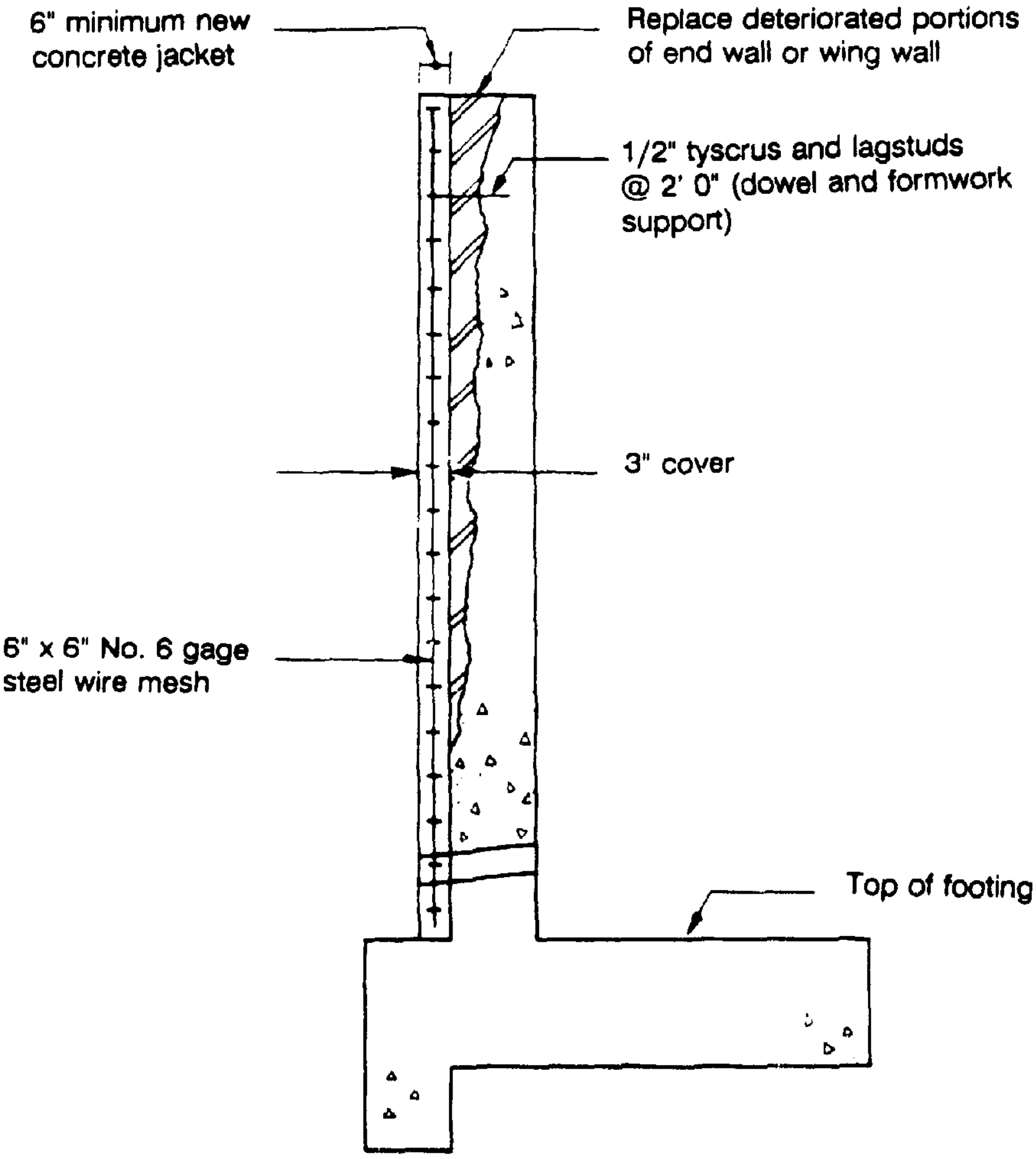
4. Just prior to placing concrete, apply epoxy bonding agent.

5. Place cement concrete, cure, remove forms, and provide erosion control as shown in figure B.19.1.

RESOURCE COMMITMENT = 1:	5 Heavy	4	3 Medium	2	1 Low
COST RELATIVE TO REPLACEMENT = 1:	5 High	4	3 Medium	2	1 Low

REFERENCES

1. Martin C. Rissel, John P. Taylor, and Robert J. Vollmer, *Procedures and Standards for Bridge Maintenance*, Final Report, Research Project 86-08 Pennsylvania Department of Transportation, June 1990.



TYPICAL SECTION

Figure B.19.1. Jacketed endwall or wingwall.(1) (adapted)

APPENDIX B-20. PROCEDURES FOR UNDERPINNING

APPLICATIONS

The following procedures have application to underpinning portions of hydraulic structures including footings, wingwalls, and the upstream end of culverts.

COMMENTS

Underpinning is the process of increasing the support for structures that have deteriorating or inadequate soil support. The cause may be scour and erosion of soil from under the structural footings or the structure may have been constructed without adequate soil support. Although several concepts may be used for reinstating or increasing the structural support by underpinning, the most appropriate will depend on the site conditions and the type of repair or retrofit work that must be accomplished.

PROCEDURES

Several concepts and methods may be used for underpinning portions of hydraulic structures depending upon the nature and severity of the problems. The following are general guidelines that may be used as the basis for the work to be done.

1. General Procedure

    a. Construct a sandbag cofferdam to an elevation above the water level or divert stream using temporary pipes.

    b. Clean all exposed concrete of marine growth and remove loose or deteriorated concrete.

    c. Excavate to a depth of two feet below the bottom of the scour or as directed by the engineer as shown in figure B.20.1.

    d. Drill required dowel holes, set and install dowels, set additional reinforcing, and place and anchor forms.

    e. Place and consolidate the concrete, making sure that the scour area is completely filled.

    f. Remove forms and (as necessary) protect against continued streambed erosion with gabions or stone riprap. Where the scoured-out material is fine-grained, a properly designed filter should be placed prior to placing the riprap.

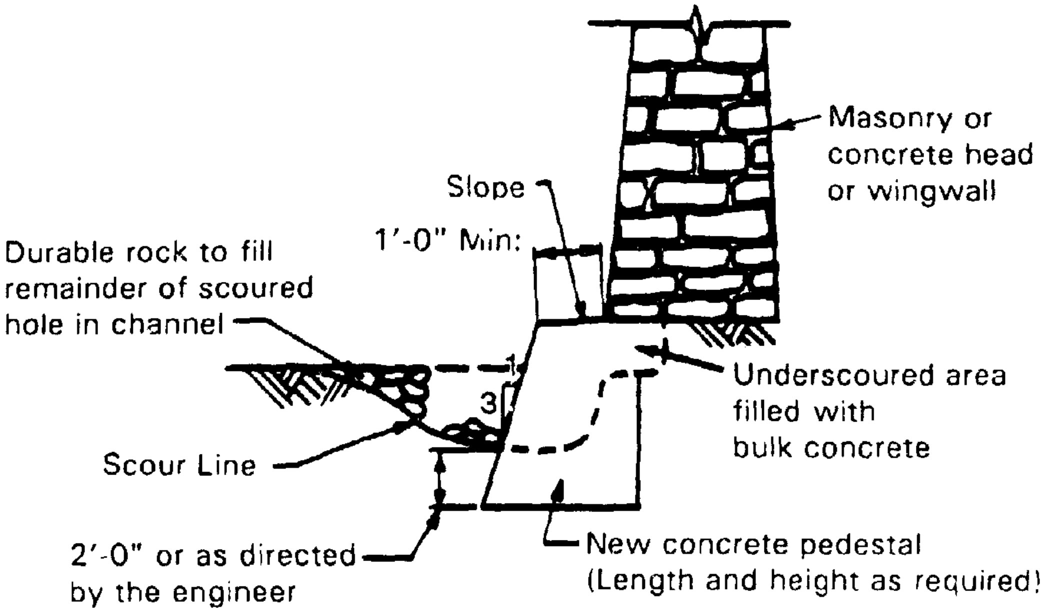


Figure B.20.1. Underpinning foundations with concrete.

2. Use of Tremie Concrete Procedures

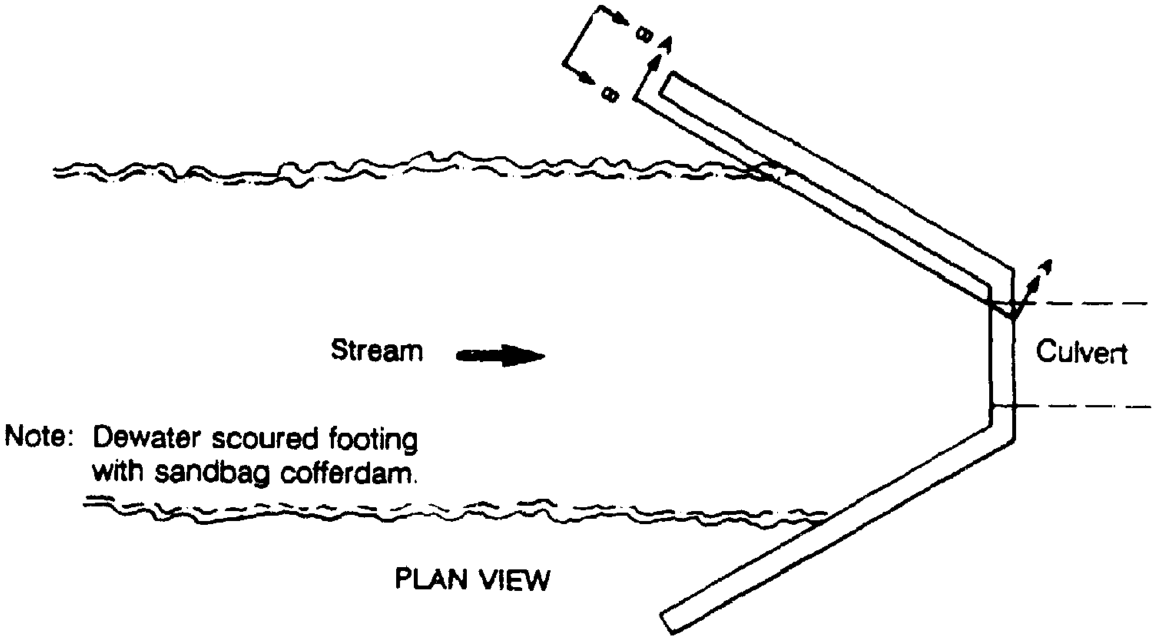
   a. Clean all exposed concrete of marine growth and remove loose or deteriorated concrete.

   b. Excavate as required to sound material.

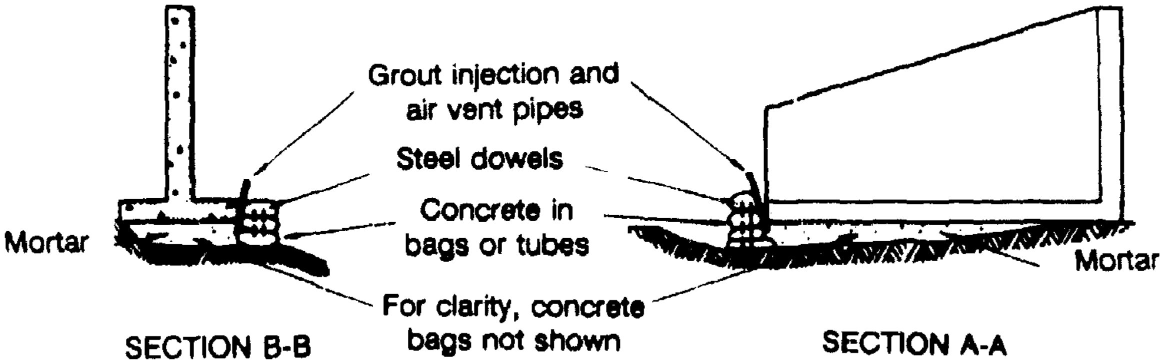
   c. Place concrete riprap bags around scour area. Where the scoured-out material is fine-grained, a filter should be placed prior to placing the riprap as shown in figure B.20.1.

   d. Pump or tremie concrete into damaged area.

   e. Protect against continued streambed erosion as required by rebuilding the streambed with properly designed riprap or by paving the streambed. Where the scoured-out material is fine-grained, a properly designed filter should be placed prior to placing the riprap.



PLAN VIEW



SECTION B-B

SECTION A-A

Figure B.20.2. Repair of scour damaged wingwall using concrete filled bags or tubes and tremie concrete.

PRECAUTIONS

1. Compliance with applicable permit and procedural requirements of fish and wildlife and conservation organizations may be required.

2. Caution must be exercised that the structure does not collapse during the repair period. Dewatering of wall structures eliminates water pressure on that side of the structure, which could allow active soil pressure on the back side of the wall to push the wall over, particularly if a large portion of the footing is undermined. It should also be recognized that dewatering for a period of time may allow soil under a footing to dry and shrink away from the underside of the footing.

3. If concrete is used to fill undermined sections of a footing, appropriate formwork should be used so that the void may be overfilled; this action will help ensure that the void is completely filled. If possible, vibrators should be used to help consolidate the concrete and to eliminate pockets of entrapped air.

RESOURCE COMMITMENT = 3:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. *Rehabilitation and Replacement of Bridges on Secondary Highways and Local Roads*, NCHRP Report 243, Transportation Research Board, December 1981.

2. *Procedures and Standards for Bridge Maintenance*, Report FHWA-PA-89-39+86-08, Pennsylvania Department of Transportation, June 1990.

APPENDIX B-21: PROCEDURE FOR REPOINTING MASONRY

APPLICATIONS

The following guidelines and procedures apply to repointing or remortaring masonry walls and culverts.

COMMENTS

Masonry walls and culverts of laid-up stone or brick are subject to having the mortar joints eroded by the effects of mortar deterioration, freeze-thaw cycles, and channel flow. Replacing the mortar, repointing, is necessary to maintain structural integrity. Repointing by this procedure should be attempted only above the water line. Therefore, accomplishment during periods of low water is recommended to gain maximum access.

Repointing masonry should be performed in accordance with plans, specifications, and procedures that are established for each specific project. The work area may include the entire length of an existing masonry culvert or only portions of it. It may also include the construction of sluices, or other means to conduct water through the structure, to protect the work area and freshly placed concrete mortar from flowing water during and after the repointing operation.

When protective material, such as riprap, is excavated to gain access to the work, it should be replaced in conformance with existing standards and procedures or procedures established for this specific project.

PROCEDURES

1. Thoroughly clean masonry joints of all loose and unsound mortar and foreign material. Deteriorated mortar may be removed by hand or power tools. Surfaces to be mortared should be cleaned with high pressure water, air-blasting, or sand-blasting, as appropriate and necessary.

2. Saturate the joint surfaces with clean water before applying mortar.

3. Pressure grout all voids between masonry units with mortar, making the surface of the mortar flush with the adjacent face of the structure, as shown in figure B.21.1.

4. Cure all new mortar with wet burlap or clear curing compound.

5. Clean the face of the masonry structure.

If used, pressure grouting should be performed by experienced pressure-gun operators.

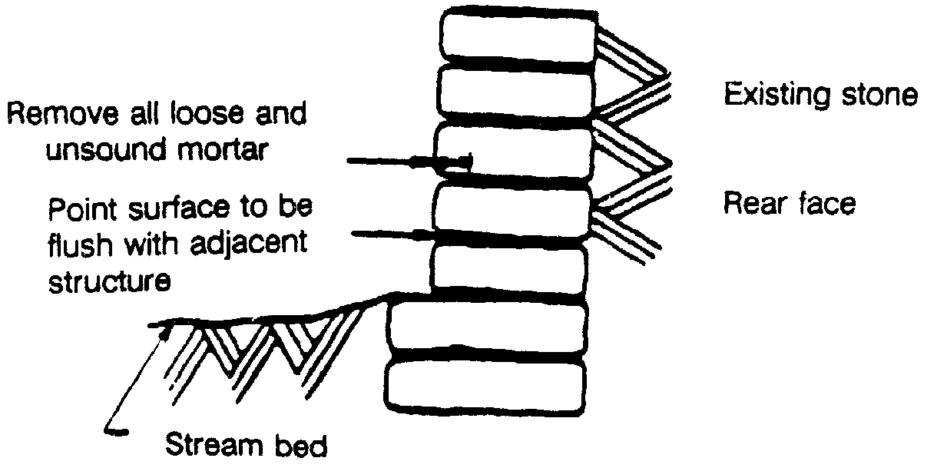


Figure B.21.1. Details for repointing masonry.[1] (adapted)

PRECAUTIONS

1. Weep holes are frequently built into masonry walls so that water and water pressure does not build up behind the wall. These weep holes may appear to be areas of missing grout. Caution should be exercised that these weep holes are not grouted closed, because closure of them could cause an otherwise stable wall or culvert to become unstable due to hydrostatic pressure.

2. Special precautions and permits may be required for general construction in streams that are inhabited or used by fish and wildlife, particularly with regard to:

   Placement of Portland cement concrete
   Sedimentation and/or erosion of soils

3. Grouting work should be performed in accordance with criteria used for conventional Portland cement concrete work, with regard to air temperature, rain, and likelihood of freezing.

4. If freezing weather is to be expected, the mortar should contain air entrainment. Some State highway agencies recommend 10 to 15 percent air.

RESOURCE COMMITMENT = 1:	5 Heavy	4	3 Medium	2	1 Low
COST RELATIVE TO REPLACEMENT = 1:	5 High	4	3 Medium	2	1 Low

REFERENCES

1. Richard E. Weyers and Richard E. McClure, A *Collection of Attempted Maintenance Force Remedial Bridge Work,* Report FHWA/PA-84/003, Pennsylvania Department of Transportation.

2. *Procedures and Standards for Bridge Maintenance,* Report FHWA-PA-89-39 + 86-08, Pennsylvania Department of Transportation, June 1990.

3. *Specification for Concrete Masonry Construction,* AC1531.1-76, American Concrete Institute, Revised 1983.

4. *Standard Specification for Grout for Masonry,* ASTM C-476.

5. *Standard Specification for Aggregates for Masonry Grout*, ASTM C-270

6. *Standard Specification for Mortar for Unit Masonry*, ASTM C-270.

7. *Standard Specification for Aggregate for Masonry Mortar,* ASTM C-144.

APPENDIX B-22. PROCEDURE FOR INSTALLING SAFETY END TREATMENTS

APPLICATIONS

The following procedure is applicable to single structures and end treatments wider than 36 inches. These structures can be made traversable for passenger-sized vehicles by using bar grates or pipes to reduce the clear opening width.

COMMENTS

Typically, culvert inlets and outlets consist of concrete headwalls and wingwalls for larger structures and beveled end sections for the smaller pipes. These types of designs may represent an obstacle to motorists who run off the road by introducing a fixed object protruding into an otherwise traversable embankment or an opening into which a vehicle can drop, causing an abrupt stop. Three alternatives can be used to minimize these hazards: (1,2)

- Use a traversable design;
- Extend the structure so that it is less likely to be hit; and
- Shield the structure.

This procedure will focus on the first option. The AASHTO Road Design Guide directs that single structures and end treatments wider than 36 inches can be made traversable for passenger vehicles by installing bar grates or pipes spaced on 30-inch centers to reduce the clear width opening. Crash tests have shown that passenger vehicles can cross grated culverts and sections on slopes as steep as 3:1, at speeds as low as 20 miles per hour when steel pipes spaced on 30-inch centers are used.

However, safety treatments must be hydraulically efficient. The AASHTO Model Drainage Manual states that culverts greater than 30 inches in diameter shall be:

> "safety treated with a grate if the consequences of clogging and causing a potential flooding hazard is less than the hazard of vehicles impacting an unprotected end. If a grate is used, an open area shall be provided between the bars of 1.5 to 3.0 times the area of the culvert entrance."

The AASHTO Road Design Guide stresses that, to maintain hydraulic efficiency, bar grates may be applied to flared wingwalls, flared end sections, or to end sections that are larger in size than the main barrel. The bottom line is that if significant hydraulic capacity or clogging problems could result, the designer should consider shielding the structure.

PROCEDURE

1. Determine the span length of the pipe to be installed. Select the correct diameter of pipe to be installed from table B.22.1.

Table B.22.1. Required pipe diameter for variable span lengths.

Span Length (ft)	Inside diameter (in)
Up to 12	3.0
12 to 16	3.5
16 through 20	4.0
20 or less with center support	3.0

2. Check the hydraulic capacity of the culvert with the addition of the bars. It may be necessary to apply bar grates to flared wingwalls, flared end sections, or to culvert extensions that are larger in size than the main barrel to maintain hydraulic efficiency.

3. Set forms for endwalls, culvert extension, wingwall, and apron, as required, matching the inlet to the slopes, as shown in figure B.22.1.

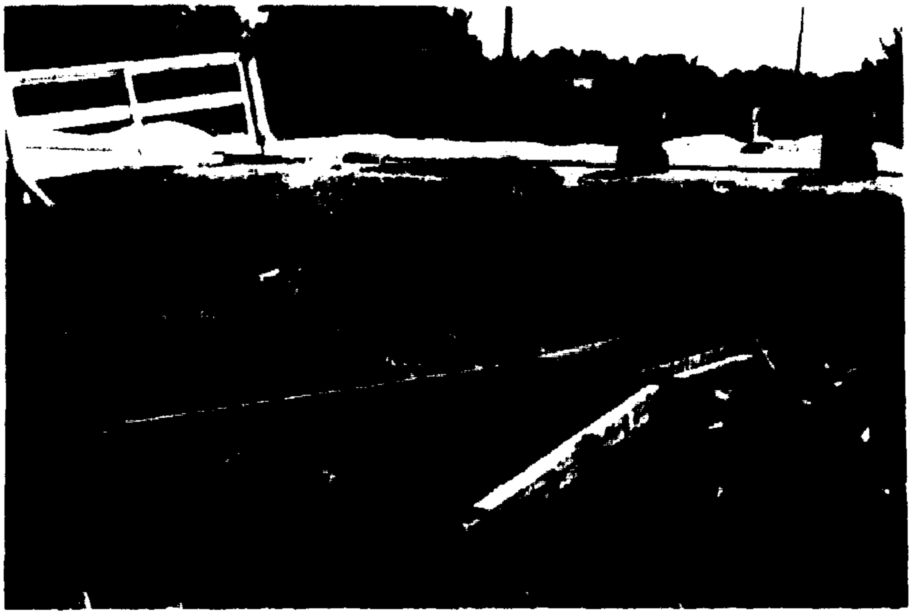


Figure B.22.1. Forms set for culvert extension and apron.

4. Set anchor bolts into the formwork for securing pipes as shown in figure B.22.2.

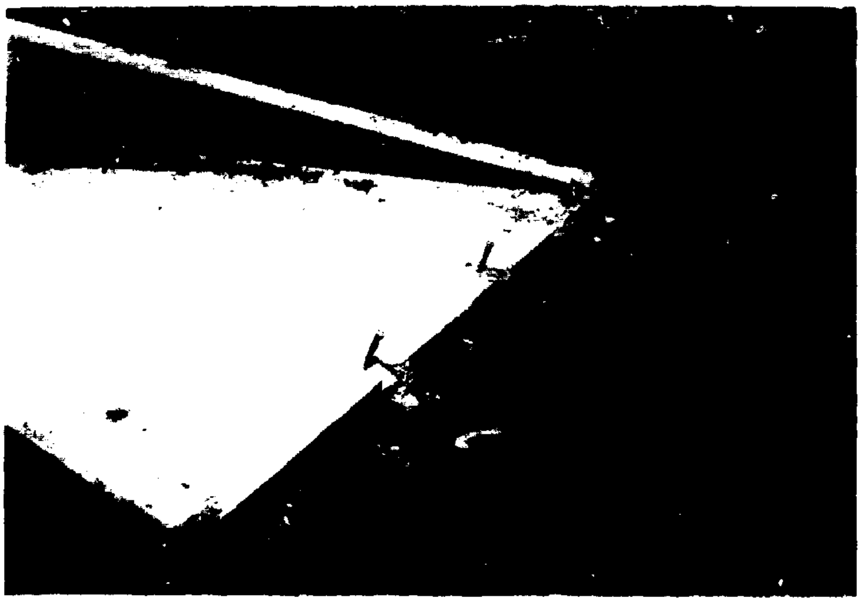


Figure B.22.2. Installation of anchor bolts to secure pipe at end of apron.

At the endwall, pipes can be welded onto a crossmember secured to the top of the wingwall by another set of anchor bolts, as shown in figure B.22.3.

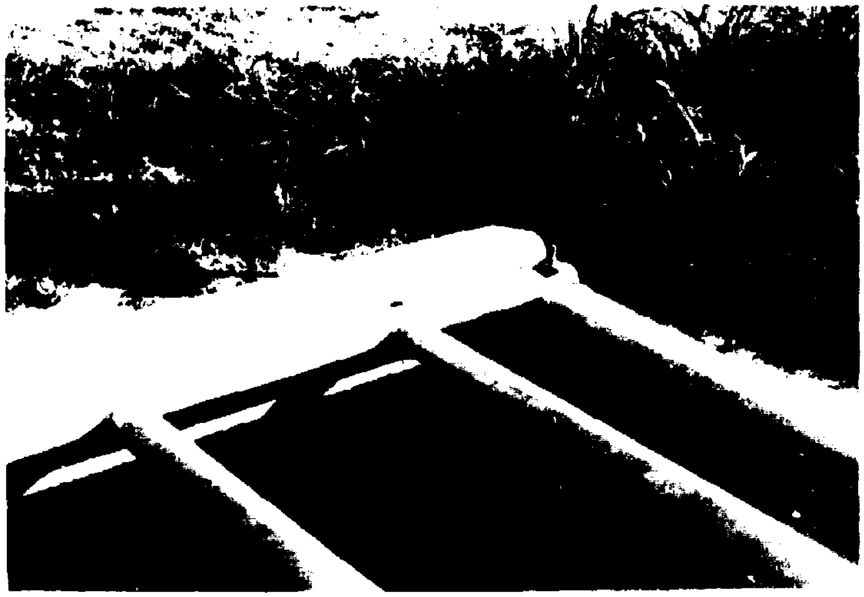


Figure B.22.3. Method of securing pipes to endwall.

In a second type of installation, pipes can be secured to a female pipe fitting set into the concrete, as shown in figure B.22.4.

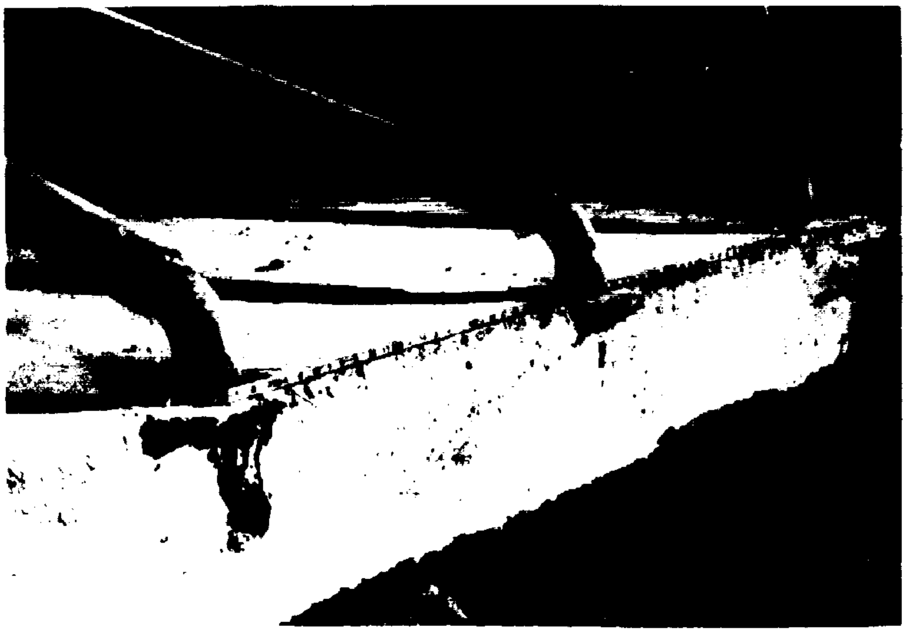


Figure B.22.4. Pipe fit into a female pipe sleeve.

5. Finish side slopes so that it is traversable. As stated in the AASHTO Roadside Design guide,

> "the toe of the embankment slope and the ditch or stream bed area immediately adjacent to the culvert must be more or less traversable if the use of grate is to have any significant safety benefits. Normally, grading within the right of way limits can produce a satisfactory run out path."

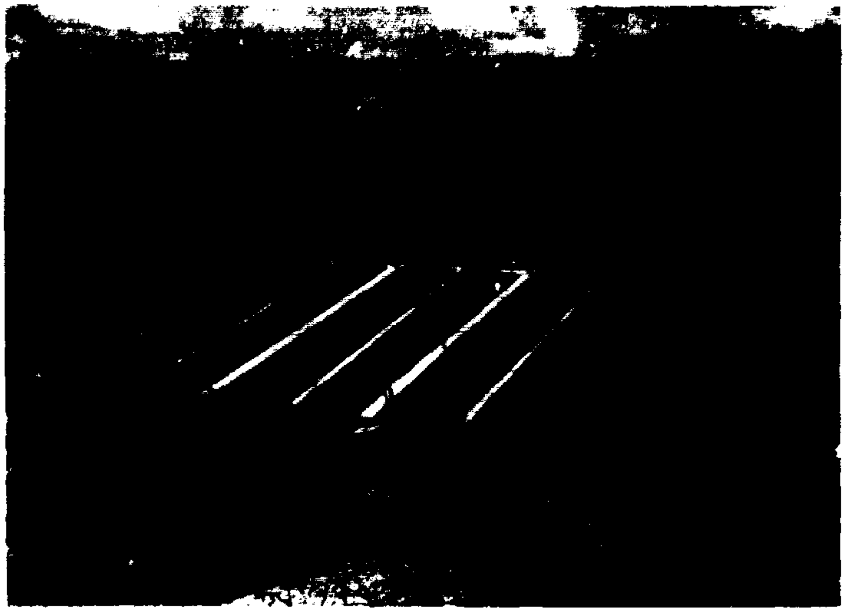


Figure B.22.5. A completed installation.

RESOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = *:	5	4	3	2	1
	High		Medium		Low

* Not applicable

REFERENCES

1. *Model Drainage Manual*, American Association of State Highway and Transportation Officials, Washington, D. C., 1991.

2. *Roadside Design Guide*, American Association of State Highway and Transportation Officials, Washington, D. C., 1989.

APPENDIX B-23: PROCEDURES FOR FACILITATING FISH PASSAGE

APPLICATIONS

The following information applies to the design of new culverts as well as to the retrofitting of existing culverts to facilitate fish passage.

COMMENTS

Culverts and other drainage structures represent a variety of potential obstacles to fish passage. The two most common of these problems are excessive water velocities through the culvert or vertical barriers that are too high for fish to overcome. Perching, which is the tendency of a stream to develop a falls or cascade at a culvert outlet due to the erosion of the stream channel downstream from a culvert, is commonplace.

Other problems may include:

- Depth of water in the culvert at high, moderate, or low flows;
- The coincidence of design flows with seasonal time of fish migration;
- The size and species of fish passing through the culvert;
- The velocity of water over a given length of structure in relation to the swimming capabilities of the fish; and
- Icing and debris problems.

In addition to the conditions in existing culverts that presently block or hinder fish passage, there are literally millions of culverts approaching the end of their useful life. If the structure is presently only marginal for fish passage, repair or retrofitting of these structures can further block the remaining fish runs.

PROCEDURES

In this section, general guidelines are given for both the installation of new culverts and for retrofitting existing culverts to improve fish passage. these guidelines are discussed in more detail in *Fish Passage Through Culverts*,(1) prepared by the U.S. Department of Agriculture Forest Services for the Federal Highway Administration.

1. General Culvert Installation Guidelines for Effective Fish Passage

    a. Culverts should be designed and installed to keep the velocity of the water passing through the pipe equal to the predicted stream velocity at design flows.

b. The culvert should maintain the natural gradient of the stream in order to avoid turbulence and scour However, if the gradient of the stream is steep, resting pools should be provided.

c. Bottomless arch culverts or partially buried pipes are preferred over round pipes, especially if:

   - The culvert is over 100 feet in length;
   - Threatened or endangered species of fish reside in the stream; or
   - The natural stream gradient is steep enough that velocities cause downstream erosion or scour at the culvert outlet.

   The most desirable culvert bottom is one consisting of the natural streambed or native materials.

d. Corrugated metal culverts generally reduce velocities and allow juvenile fish to utilize the corrugations as resting areas as they migrate.

e. Where fish passage is critical, pipe having the largest corrugations possible can be used to reduce velocities and provide a resting place:

   - 6 x 2 inch for steel structural plate;
   - 9 x 2 1/2 inch for aluminum structural plate; and
   - 5 x 1 inch for corrugated metal pipe.

f. The water depth for effective fish passage should be not less than six inches for resident trout and at least twelve inches for adult anadromous fish.

g. The use of concrete aprons at culvert openings is not recommended. The lower roughness coefficient and steeper gradient of the apron increase the velocity of the outlet. Depth of flow can also be a problem with concrete aprons.

h. The alignment and location of the culvert are important to effective fish passage because sudden changes in stream flow direction can cause turbulence resulting in scour and erosion of the streambank, and undermining of culvert inlets or outlets. Ideally, a stream channel should have 100 feet of straight alignment above and below the culvert.

i. Construction of cutoff walls attached to the bottom of the culvert and extending perpendicular to the streambed can prevent the undermining of culverts.

j. In streams with critical migratory fish needs, an outlet pool with tailwater control should be designed and constructed at the downstream end of the culvert. The length and width of the outlet pool should be twice the diameter of the culvert (2D) and the bottom elevation of the pool should be at least two feet below the invert elevation of the culvert outlet.

2. General Guidelines for Retrofitting Culverts for Improved Fish Passage

The need for any of these devices should be determined by a biologist and designed by an engineer.

a. Addition of baffles - Although the addition of baffles to a culvert should only be considered as a last resort, baffles can be **advantageous** in the following respects:

- A baffle system can produce a pocket of low velocity water in the culvert where fish can momentarily rest during high flows.
- When culverts have been placed in streams with steep gradients, velocities passing through the culvert may exceed the maximum velocity allowable for fish passage. Adding baffles may be necessary to reduce the velocity.
- The addition of baffles will change the operation of a culvert from inlet to outlet control. Those originally operating under outlet control will continue to do so.
- In addition to the value of baffles in controlling velocity, they increase water depth in the pipe to provide fish passage during low flow periods.
- A culvert with a steep gradient can be converted into a series of pools, in effect, creating a modified fish ladder.

The **disadvantages** of adding baffles include the following:

- Baffles can significantly reduce the hydraulic efficiency of a culvert;
- The design life of baffles is typically substantially less than the culvert itself. They require periodic maintenance and can significantly reduce the life expectancy of the culvert.

- Corrugated metal pipes and pipe arches are designed as flexible structures. Unless the baffle system is equally flexible, the system will have a higher potential for structural failure than the pipe itself.

- Metal baffles are normally bolted onto the culvert floor using metal plates for added strength. Simply bolting the baffle to the culvert floor is inadequate. It usually pulls loose during flood flows.

- A minimum culvert diameter of five feet is required in round metal culverts to provide a four foot wide space for baffle installation. Culverts that are less than five feet in diameter should generally not be equipped with baffles.

- The addition of baffles may not always be cost effective. Both installation and maintenance expenses should be considered before retrofitting a structure with baffles.

b. Raising the tailwater to overcome perching - An insurmountable barrier often is presented to migrating fish when the outlet of the culvert is so far above the tailwater elevation that fish cannot enter the culvert outlet. Solutions may include the following:

  - A perching problem can be corrected by installing one or a series of low head dams below the culvert outfall. These dams can consist of gabions, concrete sills, logs, or handplaced rock. If the culvert barrier is excessive, it may be necessary to install several of these dams to raise the tailwater to within one foot of the pipe.

  - Low head dams also can provide a resting pool for fish before they enter the culvert.

  - The backwater also reduces the velocity at the culvert outlet.

  - The resting pool acts as an energy dissipator and provides a transition zone between the culvert and the natural channel downstream.

  - By creating a backwater with these dams, adequate water depth is maintained in the culvert. However, since back water decreases culvert capacity, care must be taken to ensure that the culvert will pass peak flows.

c. Overcoming inlet drops - Deposition of natural streambed material or material from adjacent embankments at the culvert inlet can result in supercritical flow conditions, creating a hydraulic jump within the culvert. Although fish may have progressed through the culvert to the inlet, the turbulence and increased velocity may make it impossible to proceed for some species. One publication that may be helpful in avoiding inlet drops is *Design of Depressed Inlet Culvert.* Alaska Department of Transportation and Public Facilities.(2)

d. Debris control - Debris control is important to fish migration because debris partially blocking the culvert inlet can cause an increase in velocity that certain species cannot overcome. Chapter 5 of this manual discusses debris control structures. Additional information is also available in Hydraulic Engineering Circular (HEC), No. 9, *Debris Control Structures.* Federal Highway Administration.(3)

Additional helpful literature on fish passage is listed in the references.

PRECAUTIONS

Compliance with applicable permit and procedural requirements of fish and wildlife and conservation organizations may apply to construction and retrofit work in fishery waters.

RESOURCE COMMITMENT = *:	5 Heavy	4	3 Medium	2	1 Low
COST RELATIVE TO REPLACEMENT = *:	5 High	4	3 Medium	2	1 Low

*Varies according to type procedure selected.

REFERENCES

1. Calvin O. Baker and Frank E. Votapka, *Fish Passage Through Culverts*, Report No. FHWA-FL-90-006, Federal Highway Administration, Washington, DC, November 1990.

2. Mark C. Jordan and Robert F. Carlson, *Design of Depressed Inlet Culverts*, Department of Transportation and Public Facilities, Fairbanks, AK., June 1987.

3. G. Reiksen and L.J. Harrison, *Debris Control Structures*, Hydraulic Engineering Circular No. 9, Federal Highway Administration, Marcy 1971.

4. V. Blevins and R. Carlson, *Retrofit Design of Drainage Structures for Improved Fish Passage: Literature Review*, Report AK-RD-89-02, University of Alaska, Institute for Northern Engineering, Alaska Department of Transportation and Public Facilities, June 1988.

5. *Fish Migration and Fish Passage - A Practical Guide to Solving Fish Passage Problems*, Report EM-7100-12, U.S. Department of Agriculture, Forest Service, Revised June 1980.

6. D. Kane and P. Wellen, *A Hydraulic Evaluation of Fish Passage Through Roadway Culverts in Alaska*, Report AK-RD-85-24 and 24A, University of Alaska, Institute for Northern Engineering, Alaska Department of Transportation and Public Facilities, August 1985.

7. *Roadway Drainage Guide for Installing Culverts to Accommodate Fish*, Alaska Region Report Number 42, U.S. Department of Agriculture, Forest Service.

APPENDIX B-24: PROCEDURES FOR INSTALLING BEAVER CONTROL DEVICES

APPLICATIONS

The following methods are applicable to the installation of appurtenances to prevent beavers from plugging culvert inlets.

COMMENTS

The easiest way for a beaver to construct a dam in a waterway is to plug a culvert inlet. The result is often a washed-out roadway. Because of the persistent problem and the cost of keeping culverts clear, the San Dimas Equipment Development Center of the U.S. Forest Service tested and evaluated the following methods of beaver control in the Ottawa National Forest in northern Michigan. Each approach is based on two traits characteristic of beavers:

1. They normally do not try to plug a culvert if the area to be plugged is much greater than the culvert opening itself.

2. They usually will not try to plug an opening through which water flows vertically upward.

PROCEDURES

The four structural methods presented below include (1) the perforated pipe method, (2) the perforated culvert method, (3) the downspout method, and (4) the baffle method.

1. The Perforated Pipe Method: The theory behind this method is that, although the beaver may build a dam in the culvert entrance, water can still flow through the perforations and out the pipe downstream of the dam. The beaver may plug some of the perforations but usually not all. This type installation is illustrated in figure B.24.1.

    a. Place a piece of perforated pipe with one end inside the culvert inlet and the other end extending upstream, well beyond the culvert entrance.

    b. Install a cap or plug on the upstream end of the perforated pipe.

    c. To allow for a larger volume of water flow, more than one pipe may be used or a "Y" or "T" section in the pipe upstream of the culvert so that extra arms of perforated pipe can be installed.

    d. The pipe or pipes can rest on the bottom of the culvert interior. However, it should be supported above the bottom of the stream. A stake or a cross bar supported by two stakes can be used. The pipe should be anchored to prevent the end from drifting.

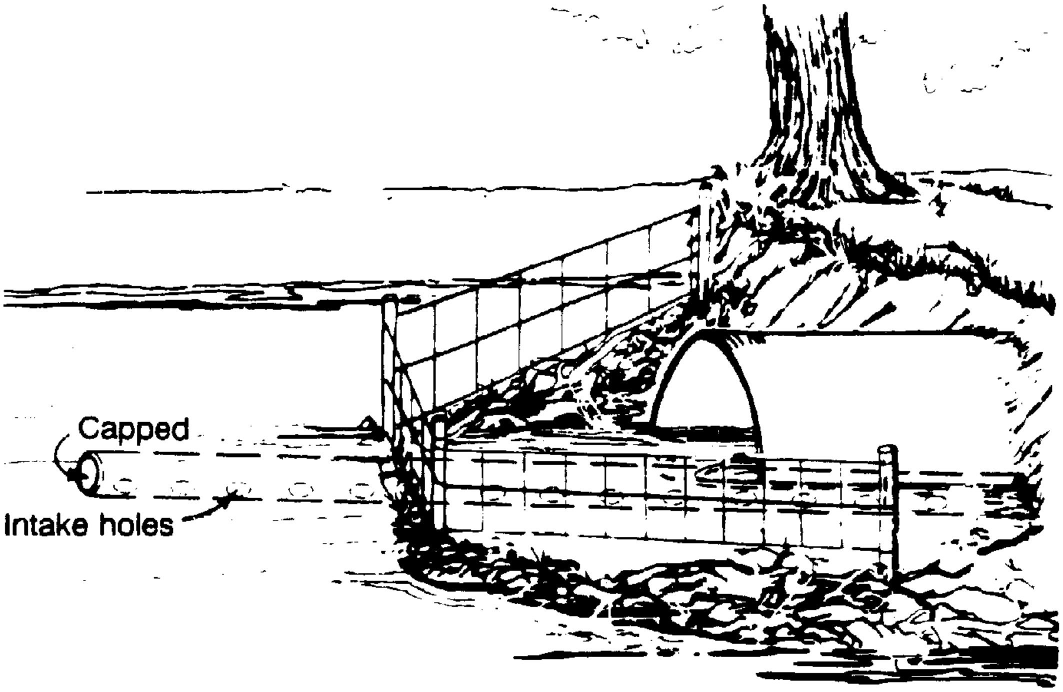


Figure B.24.1. The perforated pipe method.

e. As an additional step, a baffler or fence constructed of 12.5 gauge wire-mesh fencing, well supported with stakes, can be built around the culvert entrance. The fence is generally horse-shoe shaped. The perforated pipe or pipes can be passed through a hole in the fence.

f. Stakes supporting the fence should be studied and installed so that high water does not dislodge them. Beavers will often build their dam around the fence but it is easier to remove debris from the fence than inside the culvert. Quite often, after the beavers realize they are unable to maintain a high water level behind the dam, they become discouraged and move on.

2. <u>The Perforated Culvert Method</u>: In this method of beaver control, a short length of specially designed same-diameter culvert, as shown in figure B.24.2, is added onto the end of the culvert already in place. Since the water will flow upward through the holes cut into the bottom of the attachment, beavers will not plug these holes. However, if they do become plugged or if the flow of water increases greatly, water can flow into the end

of the culvert extension as soon as the water level rises over the four-inch welded plate lip. Steel mesh or bars can be welded over the sloping opening to keep beavers from entering the culvert for dam-building purposes.

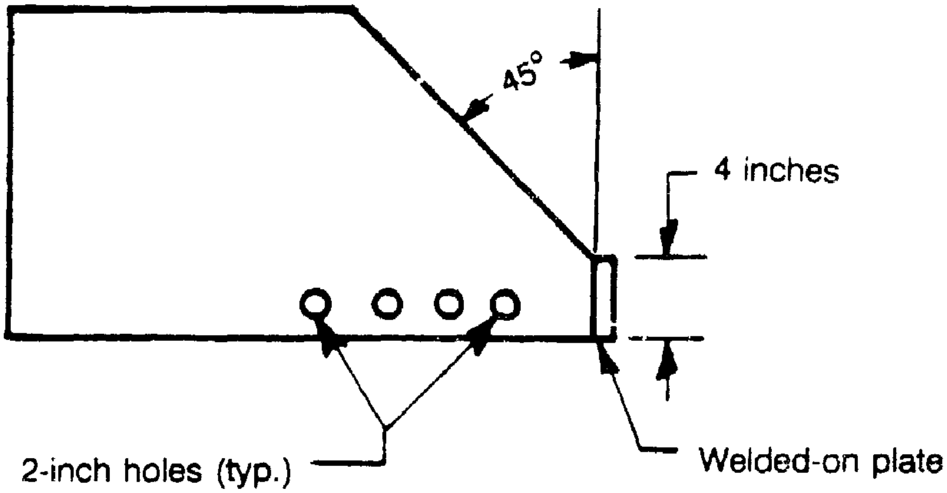


Figure B.24.2. Perforated culvert method.

3. The Downspout Method: In this method, a section of culvert is cut at a 45-degree angle and welded to the remainder of the culvert to form a 90-degree angle as illustrated in figure B.24.3. When this section is attached to the in-place, existing culvert with the right-angle section pointing downward, water will rise vertically to flow through the culvert. The attachment should be installed to extend downward as far as possible without picking up debris from the bottom of the stream or impoundment. Steel mesh or bars should be welded across the opening to prevent beavers or large debris from getting inside.

4. The Baffle Method: The baffle or fence method of preventing beavers from reaching culvert inlets shows potential for culverts larger than five feet in diameter. It can also be tried at locations where a fast-flowing or shallow stream precludes other approaches. This method is illustrated in figure B.24.4.

   a. Construct a box fence around the culvert inlet opening.

   b. Extend two parallel fences, three feet apart, upstream from the box fence for approximately 30 feet and join their ends together.

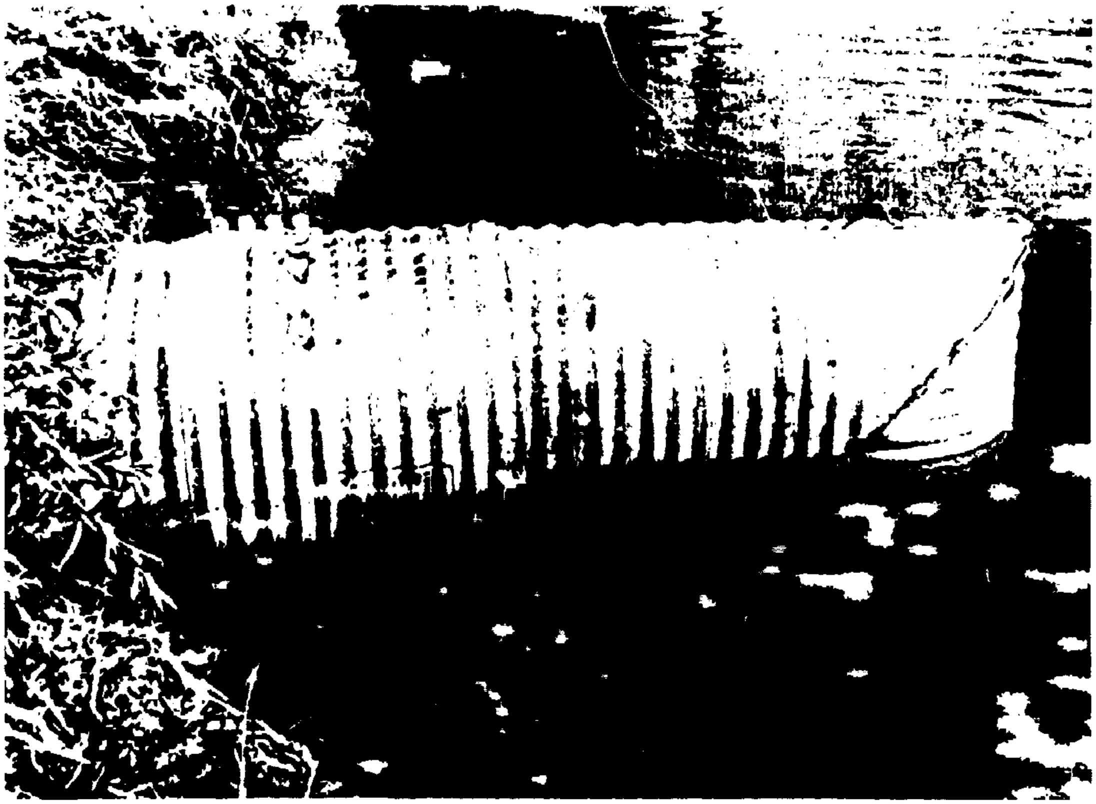


Figure B.24.3. Downspout method.

c. Fabricate the fences from 12.5-gauge wire mesh with approximately four-inch openings. Support the fences on steel posts, driven at least three feet into the streambed.

   In order to construct a dam, the beavers must construct a dam around the entire length of the fence; usually they will not attempt this.

5. Beaver Baffler: An article in *Oregon Roads* suggested a simple, non-structural method of preventing beavers from building dams. Place a 36-inch by 36-inch white flag fastened at the top between poles at any location at which a beaver is initiating dam construction or in the area where a dam has been removed. The color and motion seem to deter further activity by the beaver.

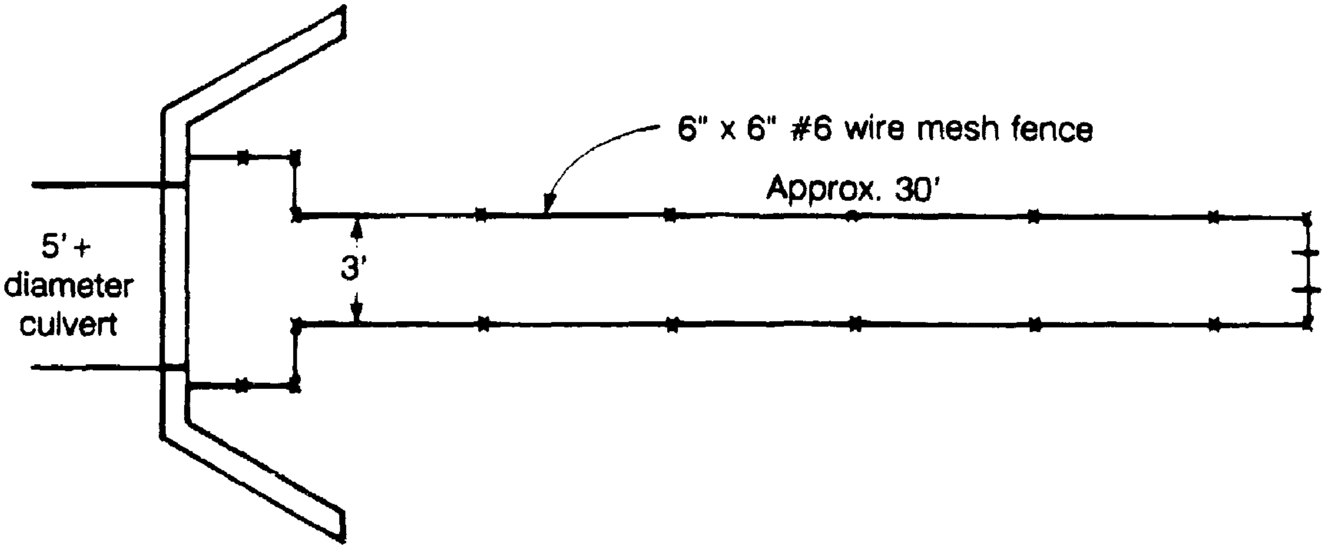


Figure B.24.4. Baffle or fence method.

SAFETY PRECAUTIONS

The specific method to be used at any site depends upon such conditions as the flow rate and depth of the water. The specific design of the approach must take into consideration hydraulic efficiency to ensure that full water flow will be accommodated.

RESOURCE COMMITMENT = 1:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. Phillip H. Fisher, "Keeping Beavers from Plugging Culvert Inlets." *U.S. Forest Service Engineering Field Notes - Volume 18*, January-February 1986.

2. *Wisconsin Beaver Damage Control Guidelines*, PUBL-WM-007 86 REV, Wisconsin Department of Natural Resources, October 1986.

APPENDIX B-25: PROCEDURES FOR REPAIRING CRACKS IN CONCRETE

APPLICATIONS

The following discussion applies to the repair of cracks in Portland cement concrete.

COMMENTS

The procedures and materials that should be used for repairing cracks in Portland cement concrete will frequently depend upon the cause of the crack, its location, and the environment surrounding it. Shrinkage cracks may be quite narrow and shallow and have little influence on the structural behavior, whereas wider and deeper cracks may have been caused by structural loading and may signify more serious effects on structural load carrying capacity. Both types of cracks may have an influence on long term durability of the structure.

With regard to procedures for repairing cracks in concrete culverts, there is always an overall requirement that cracks be clean and preferably dry before they are repaired. Obviously, it may be difficult to meet both of these criteria for cracks in culverts. The cracks will generally be old by the time they are found, and if they are wide enough, they may be full of sand or dirt. In addition, they may be continuously wet from water from either the inside or the outside of the culvert. Thus, generally some work will be needed to prepare the crack for the repair material.

There is a choice of materials that may be used to repair cracks. The materials generally may be categorized as either flexible crack fillers or rigid materials that are more permanent that may create a structural repair. The latter group includes both Portland cement-based mortar and structural adhesives including epoxy systems that may be filled with aggregate or a powder or unfilled.

The general opinion of many practitioners is that cracks that are moving because of movement in the structure should be repaired with a flexible sealing-type material, whereas stationary cracks may be filled with a rigid material. This is not an absolute rule, but it does highlight the need to determine whether the crack is moving. For most concrete culverts it may be assumed that the crack is moving, especially since there is a close relationship between soil pressures and the resistance (and strength) of a concrete culvert; and the soil pressures that may have caused cracking will continue to be exerted on the culvert. Under some situations the condition may have stabilized. Thus, there is a rationale that the structure is probably still moving and it should be filled with a flexible material. However, there is also another principle in soil-structure behavior that if conditions are allowed to continue they will become worse, as the soil pressures will continue to deform the structure until collapse occurs. From that standpoint it may be best to try to strengthen or stabilize the

structure so that it can resist the increasing soil pressures, in this case by effecting a structural repair on the more serious cracks. This will require filling the cracks with a rigid material. If tensile, flexure of shear forces will occur it may be necessary to use a structural adhesive. Some of these materials may be installed in wet or submerged cracks.

PROCEDURES

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 will have more specific recommendations for their particular materials if the highway agency has not established such procedures.

   a. Clean the surface of the concrete.

   b. Route a groove into the surface of the crack, so that it will serve as a reservoir for the sealant.

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

   d. Fill the crack with the sealant by pressure injection or troweling. If troweling is to be done a bond breaker should be first applied to the surface of the concrete on both sides of the crack so that the sealant will not have a wide width at the top of the crack.

   e. Scrape excess sealant off the concrete surface, so that the surface will be smooth. (For some types of cracks it may be desirable to trowel a shallow depression in the surface of the sealant.)

2. Installation of a Portland Cement Mortar or Grout

   Wide cracks may be repaired by filling with portland cement grout, as follows:

   a. Clean the surface of the concrete.

   b. Install built-up seats and grout nipples at intervals along and astride the crack to provide a pressure tight contact with the injection apparatus.

   c. Seal the crack between the grout nipples, with a cement paint, sealant, or grout.

d. Flush the crack to clean it and to test the seal.

e. Grout the crack. The grout mixture may contain cement and water or cement plus sand plus water, depending on the width of the crack. 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 admixtures to improve the properties of the grout.

3. Repair by Injection of Epoxy Adhesive

The following is from guidelines of the Pennsylvania DOT.

Equipment

a. Type - The equipment used to meter and mix the two injection adhesive components and inject the mixed adhesive into the crack shall be portable, positive displacement type pumps with interlock to provide positive ratio control of exact proportions of the two components at the nozzle. The pumps shall be electric or air powered and shall provide in-line metering and mixing.

b. Discharge Pressure - The injection equipment shall have automatic pressure control capable of discharging the mixed adhesive at any preset pressure up to 200 psi plus/minus 5 psi and shall be equipped with a manual pressure control override.

c. Ratio Tolerance - The equipment shall have capability of maintaining the volume ratio for the injection adhesive prescribed by the manufacturer of the adhesive with a tolerance of plus or minus 5 percent by volume at any discharge pressure up to 200 psi.

d. Automatic Shut-Off Control - The injection equipment shall be equipped with sensors on both the component A and B reservoirs that will automatically stop the machine when only one component is being pumped to the mixing head.

Preparation

a. Surfaces adjacent to cracks or other areas of application shall be cleaned of dirt, dust, grease, oil, efflorescence or other foreign matter detrimental to bond of epoxy injection surface seal system. Acids and corrosives shall not be permitted for cleaning.

b. Entry ports shall be provided along the crack at intervals of not less than the thickness of the concrete at that location.

c. Surface seal material shall be applied to the face of the crack between the entry ports. For through cracks, surface seal shall be applied to both faces if possible.

d. Enough time for the surface seal material to gain adequate strength shall pass before proceeding with the injection.

Epoxy Injection

a. Injection of epoxy adhesive shall begin at lower entry port and continue until there is an appearance of epoxy adhesive at the next entry port adjacent to the entry port being pumped.

b. When epoxy adhesive travel is indicated by appearance at the next adjacent port, injection shall be discontinued on the entry port being pumped, and epoxy injection shall be transferred to the next adjacent port where epoxy adhesive appeared.

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

d. If port to port travel of epoxy adhesive is not indicated, the work shall immediately be stopped and the engineer notified.

Finishing

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

b. Surface seal material and injection adhesive runs or spills shall be removed from concrete surfaces.

c. The face of the crack shall be finished flush to the adjacent concrete showing no indentations or protrusions caused by the placement of entry ports.

RESOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low

COST RELATIVE TO REPLACEMENT = *:	5	4	3	2	1
	High		Medium		Low

* Varies according to procedure selected.

REFERENCES

1. "Causes, Evaluation, and Repair of Cracks in Concrete Structures," (ACI 224.1R-84) ACI Manual of Concrete Practice, American Concrete Institute, 1989.

2. Guiding documents are available from the following companies:
   a. Master Buildings (Formerly Adhesive Engineering)
   b. Sika Chemical Company

APPENDIX B-26. PROCEDURES FOR SEALING CULVERT JOINTS

APPLICATIONS

The following applies 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 the others, with some adaptation.

COMMENTS

Corrugated metal pipe and pipe arch as well as precast concrete culverts are subjected to a variety of external loads and changing soil conditions that may cause the circumferential joints to open. When this occurs infiltration and exfiltration frequently develop and cause a progressively worsening condition. Open joints lead to loss of the embankment material and creation of voids in the embankment surrounding and supporting the culvert. Uneven soil pressures may cause distortion of metal culverts and cracking and settlement of precast concrete culvert, with possible collapse of both types.

The amount and complexity of remedial action will depend upon the site conditions, the type of culvert, and the level and severity of the deterioration. Site conditions include such factors as location, height of fill over the culvert and infiltration from water under a considerable hydraulic head pressure. The solution to the problem generally involves installation of an expansion ring that bridges and closes the open joint and pressure grouting to fill voids in the soil behind the joint. The closure ring may have to carry structural loads, external hydraulic pressure, or both. The following describes techniques for the use of two types of closure rings. Information on grouts and grouting techniques is provided in appendix B, section 11.

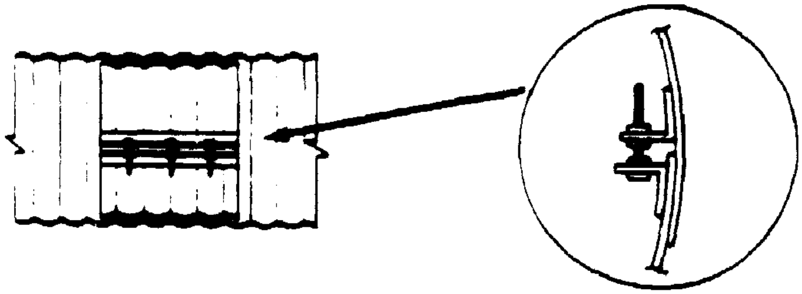
PROCEDURES

1. Steel Expansion Ring Gaskets

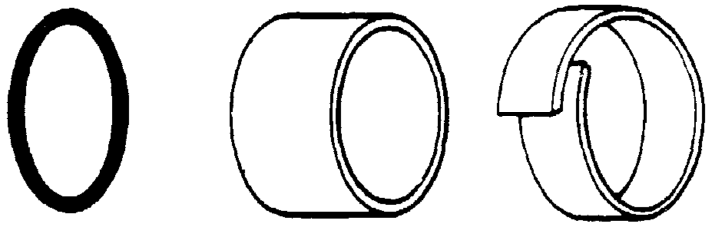
   Several types of corrugated steel expansion rings are available for repair of culvert joints from inside of the culvert, as shown in figure B.25.1

   a. 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.

   b. Based on the type and width of band selected, a gasket that will properly seal the joint is determined,i.e., an O-ring type could be used with a corrugated band; a strip type with other types of bands where minor misalignment is determined; and a mastic type with a flat band where misalignment is greater. Strip gaskets should be wider than the band.



a. Internal expanding band.



O-Ring Gasket Sleeve Gasket Strip Gasket

b. Standard steel pipe gaskets.

Type of Band	X-Section	Angles	Bar Bolt & Strap	Wedge Lock	Gaskets			Pipe End		
					O Ring	Sleeve or Strip	Mastic	Annular Plain	Helical	
									Plain	Reformed
Universal		X		X		X	X	X	X	X
Corrugated		X	X	X		X	X	X	X	X
Semi-Corrugated		X	X	X	X		X	X		X
Channel		X	X				X			X
Flat		X	X	X	X	X	X	X	X	X
Wing Channel		X	X				X			X

c. Types of bands.

Figure B.25.1. Expansion seals.[2]

c. Fabricate band(s) using 2 sections that conform to the existing pipe shape. Each section should conform as nearly as possible to 1/2 of the cross-section of the pipe, with the maximum being equal to the perimeter of the 2 sections. Shorter than 1/2 cross-section may be desirable if the two pieces are to be bolted together prior to placement at the joint. 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 3/4 inch minimum. It may be necessary to specify larger diameter bolts for some installations.

d. The peripheral area of the pipe where the band is to be placed must be cleaned and prepared. Dirt and debris should be removed. 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.

e. Install the band with gasket either with the two sections bolted together or as single 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.

f. Tighten the bolts evenly until a tight fit is realized. A tight fit may be determined by the distortion of the gasket or band-to-pipe contact. Caution: observe invert area of band for buckling.

g. Seal the edges of the band with a mastic.

SAFETY PRECAUTIONS
If galvanized metal is used for the band, removal of the galvanizing is required prior to welding clip angles. Caution should be exercised when shop or field welding is performed on galvanized metals. Fumes can be toxic. The welder should wear a mask in case all galvanizing has not been removed.

2. AMEX-10/WEKO-SEAL™ Internal Joint Sealing System

The Miller Pipeline Corporation has developed a proprietary system for the repair of water, wastewater, gas, and other types of pipelines made of reinforced concrete, cast iron, ductile iron, steel, cement lined, and unlined pipe. It has also been used by several highway agencies to repair precast and corrugated metal culverts. It has been used on pipelines from 14 to 208 inches in diameter. The standard seal can span a 4-1/2 inch gap and the double-wide seal can span a 9 inch wide gap. A particular advantage is that it can withstand a high external pressure, at least up to 100 feet of head. It may be used for a wide variety of shapes, including circular, oval, arch, and even box-shaped pipes and culverts.

This joint sealing system is comprised of a Ethylene Propylene Diene Monomer (EPDM) rubber seal into which stainless steel strips are set. The seal is resistant to weather, chemicals and bacteria. Installation of the seal involves expansion of the ring with a hydraulic jack and locking off the ring by inserting metal wedges between the ends of the stainless steel bands. A more detailed description of the installation procedure is as follows:

a. The culvert should be cleaned, at least in the area of the joints to be sealed. Generally this can be done with hand tools.

b. Gaps in the joints must be cleared of dust and debris and filled flush with the internal surface of the culvert with a quick setting mortar or grout.

c. The area of the culvert on both sides of the joint, where the "lip seals" make contact with the culvert, must be prepared to a finish that will allow the "lip seals" to bed consistently, so as to provide a permanent seal.

d. Immediately prior to fitting the seal, the area must be cleaned and coated with a joint lubricant.

e. The seal is then placed in position, parallel to the joint gap.

f. Two stainless steel-radiused shims are placed under the wedge area in grooves in the rubber seal and the stainless steel bands are installed in the grooves.

g. A hydraulic jack expander is then attached and used to expand the stainless steel bands and the rubber gasket against the inside of the culvert. After the gasket ring is expanded the wedge shims are set between the ends of the bands and the expander is retracted.

RESOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

SPECIFICATIONS

No specific specifications apply directly to this type of work. Standard specifications should be used for bands, gaskets, clip angles and hardware. Size of angles and bolts should be in accordance with AASHTO design standards.

REFERENCES

1. *Drainage Technology Bulletin*, National Corrugated Steel Pipe Association, September 1988.

2. *Handbook of Steel Drainage and Highway Construction Products*, American Iron & Steel Institute, Washington, D.C.

3. Miller Pipeline Corporation (address provided in Appendix D).

APPENDIX B-27. PROCEDURES FOR PREVENTING END SECTION DROPOFF OF PRECAST CONCRETE CULVERTS

APPLICATIONS

The following procedure may be used to prevent the dropoff of the end sections of precast concrete culverts, primarily due to erosion of the embankment around them.

COMMENTS

The problem of end section dropoff is primarily caused by erosion of the soil embankment from under the entrance or exit ends of the culvert. With a loss of soil support from under the end sections and continued soil pressure being applied by the embankment above, the only possible result is that the end sections begin to rotate and slide into the scour hole since the sections of the precast concrete culvert are not attached to one another.

The following are three concepts that may be used to connect sections together to prevent end section dropoff.

PROCEDURES

1. Use of Concrete Pipe Ties

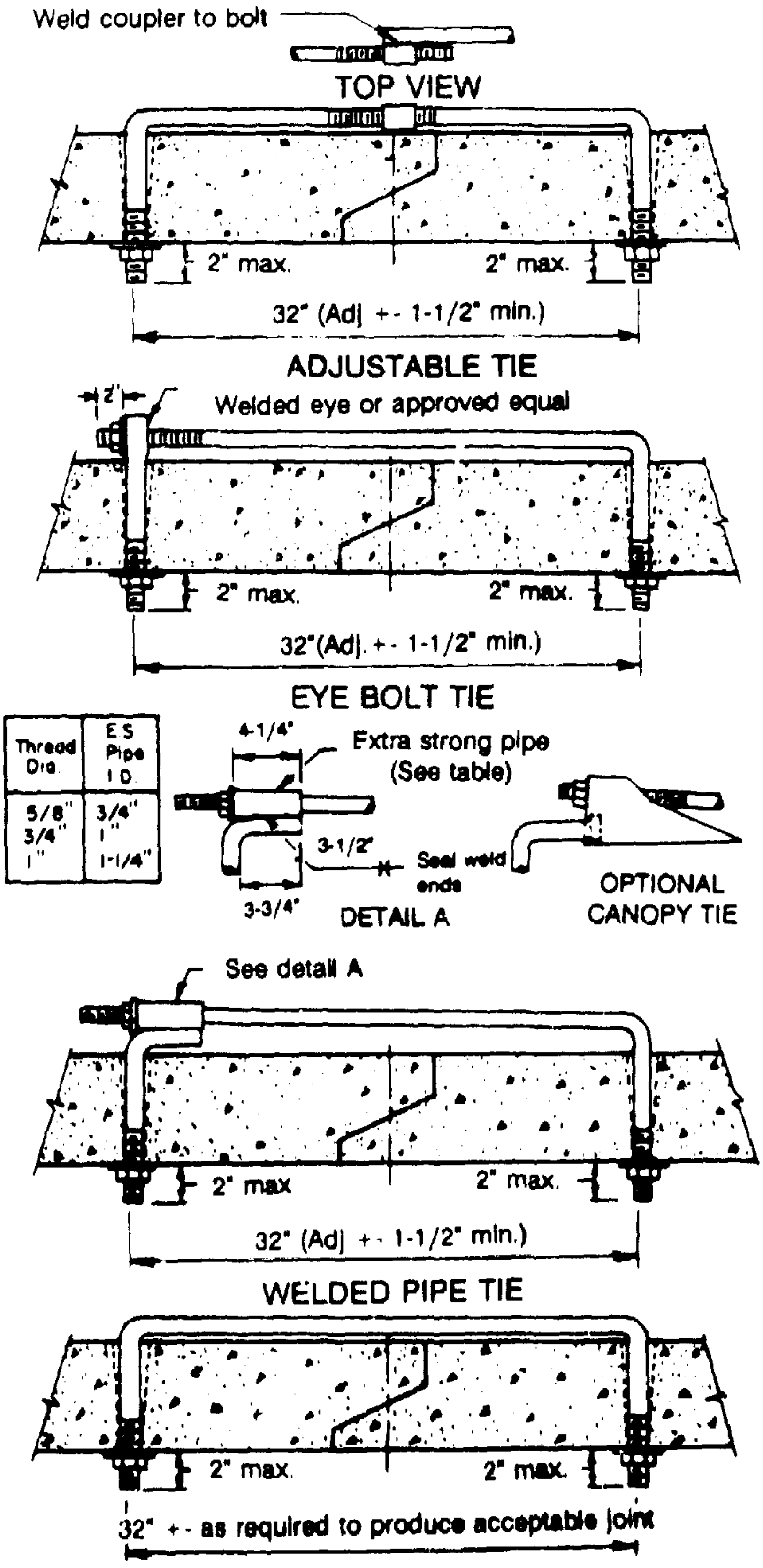
The North Dakota State Highway Department uses concrete pipe ties for most new installations to prevent end-section dropoff of reinforced concrete pipe and for repair projects where an end section(s) has separated from the other sections.

Figure B.27.1 illustrates four methods by which concrete pipe ties can be fastened to concrete end sections to secure them to the remaining pipe: (1) an adjustable tie, which consists of a coupler welded to the bolt; (2) an eye-bolt tie in which the tie is threaded through a welded eye to secure the sections; (3) a welded pipe tie where the two bolts are welded together as shown in detail A; and the U-Bolt tie in which the tie bolt is connected into the one end of each concrete section without using a joint.

Figure B.27.2 shows the placement of the holes in the concrete pipe. Table B.27.1 provides the size of the bolts required for pipe sizes from 12 inches to 132 inches. The notes shown are those that were included in North Dakota Highway Department plans for such a project.

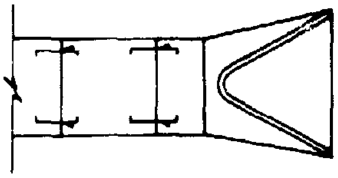
2. Use of Steel Reinforcing Bars

Some highway agencies have been installing steel reinforcing bars



Thread Dia.	E.S. Pipe I.D.
5/8" 3/4" 1"	3/4" 1" 1-1/4"

Figure B.27.1. Concrete pipe ties. Source: North Dakota State Highway Department



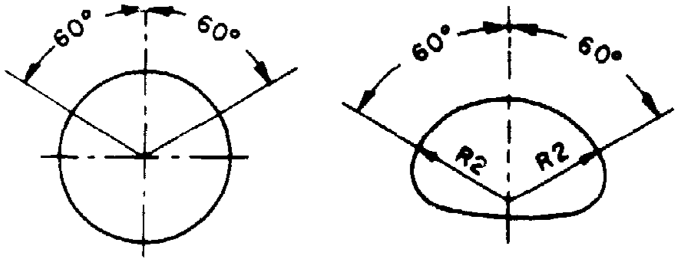


Figure B.27.2. Placement of holes.

NOTES:

1. Pipe size [illegible]ed is inside diameter of round pipe or equivalent diameter of pipe arch.
2. Nuts and washers are not required on inside of 21" diameter pipe or less.
3. Ties to be used only to hold pipe sections together not for pulling sections tight.
4. Tie bolts shall be painted after fabrication with one coat of zinc chromate iron oxide paint. Threaded portion of rods do not have to be painted.
5. Holes in pipe to accommodate the tie bolts can be precast or drilled. Tapered holes will be permitted when precast. When existing pipe are extended or salvaged and relayed, the contractor will be required to drill the necessary holes.
6. The contractor has the option of selecting the type of tie bolt to be used. The type selected shall be approved by the engineer.
7. The cost of precasting or drilling the required holes and furnishing and installing the tie bolts shall be included in the price bid for reinforced concrete pipe culverts.
8. Tie bolts are not required on storm sewer pipe unless specifically noted in the plans.
9. Tie bolts are required on end sections (4 each) for all RCP culverts. On culverts without flared end sections, the three end sections of the culvert shall be tied together in the same manner for each end.

Table B.27.1. Required size of tie bolts.

REQUIRED SIZE OF TIE BOLTS	
Pipe Size (inches)	Thread Diameter
12	5/8" (See Note 2)
15	
18	
21	
24	
27	
30	3/4"
33	
36	
42	
48	
54	
60	
66	
72	1"
78	
84	
90	
96	
102	
108	
120	
132	

PRECAUTIONS

1. If prestressing is to be installed, it should be installed by personnel and/or contractors who are familiar with such operations. Personnel who are not essential to the operation should not be allowed in the culvert at the time of stressing.

RESOURCE COMMITMENT = 1:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

APPENDIX B-28. PROCEDURES FOR PATCHING CONCRETE

APPLICATIONS

The following procedure may be used to patch spalled, delaminated and broken areas of Portland cement concrete.

COMMENTS

Although there are many materials that may be used for patching concrete, the overriding principle for such repairs is that it be done carefully and with good workmanship. The cracked, spalled, or otherwise deteriorated area to be repaired must be properly prepared, good materials must be used, and the work must be properly protected until the materials have gained sufficient strength and other physical properties to withstand the expected environmental and loading conditions. The alternative to this produces a patch that will not endure and the patching work will be a total waste of time and money. Moreover, loss of the patch may create worsening or additional problems that will certainly require even more time, material, and funding to correct. Depending upon the site conditions, even well prepared and installed patches may not last very long, and it should be an established practice to periodically inspect critical patches to ensure that the structure is performing adequately.

The material that normally provides the most permanent patch for Portland cement concrete is Portland cement concrete. The closer the physical properties of the patch are to the existing material, the better. It is important to minimize shrinkage of the patching material. This may be done by using a low water/cement ratio material. A water reducing admixture may also be used. Inclusion of a latex additive to the concrete or mortar will also reduce the amount of water required for workability and also reduce the permeability of the patch material. Other performance-proven additives can be used to reduce setting time and to increase strength.

Proper curing is important for all concrete work and especially important for patching. Thin patches present a particularly difficult problem because they dry out quickly. The existing concrete will tend to absorb the moisture in the patching material. If exposed to the sun or wind, moisture is lost even more rapidly. If possible, patches should be covered with moist burlap.

The following provides some guidance for patching portland cement concrete.

PROCEDURES

1. The first step is to determine the exact boundaries of the distressed concrete. Delaminated areas may be detected by tapping with a hammer or steel rod, with a hollow sound being produced in the delaminated area.

2. Remove delaminated and/or broken concrete from the distressed area. For some areas or structures it may be desirable to make a 3/4 inch deep sawcut around the area to be patched. For delaminated and spalled areas, the edge of the repair should be extended 12 to 18 inches into good concrete to be ensure that all cracked concrete is removed. Deteriorated concrete may be removed with power-driven hand tools. If used, pneumatic hammers should not be heavier than a nominal 30 pounds. A 15 pound chipping hammer may be useful, particularly around reinforcing bars. Care must be taken to not apply heavy vibrations to reinforcing bars, to prevent breaking bond with the concrete.

3. The repair area should then be air - or sand-blast cleaned to removal all dust and debris. Do not use water to clean the area.

4. Apply a cement or cement-latex grout or an epoxy resin to the sides and bottom of the area to be repaired.

5. Place the patching material in the distressed area, in accordance with State, ACI or the manufacturer's guidelines. The material should be placed before the bonding layer (step 4) begins to set up. The patch material should then be struck off, finished, and edged as required.

6. The patch area should then be covered with wet burlap or a moisture barrier and allowed to cure without disturbance.

RESOURCE COMMITMENT = 1:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

APPENDIX B-29. PROCEDURES FOR INVERT PAVING

APPLICATIONS

Invert paving may be installed in all types of culverts; however, different methods may be used for anchoring the concrete paving to the existing culvert.

COMMENTS

It may be appropriate or necessary to concrete pave the invert of culverts that have deteriorated because of corrosion and/or abrasion. Paving will also improve the flow characteristics and provide increased durability against further deterioration.

A variety of materials and techniques may be used, depending upon the nature of the existing problems and the type of culvert that must be rehabilitated. Invert paving may be done with conventional Portland cement concrete, steel fiber reinforced concrete, or high strength concrete as well as latex modified or low slump concretes of the type used for bridge deck overlays. As with the latter, it is also very important that the remaining invert and previous paving or protective layers be properly cleaned and prepared for placement of the invert paving. In areas where acid water will deteriorate concrete, the surface may be coated with an epoxy resin or a polymer concrete.

It should be recognized that paving to restore a severely deteriorated invert is a structural repair. At the least the cross sectional area of the lost metal (of a corrugated metal culvert) should probably be replaced so that the culvert will have structural strength to resist lateral thrust loading. Determination of the size and number of reinforcing bars used to reinforce the paving should give consideration to the lateral (hoop) stiffness of the culvert and the restoration of that stiffness.

As an alternative, instead of restoring the ring stiffness of the culvert by reinforcing the concrete paving, the Ohio DOT has welded new invert plates over the deteriorated areas and done field paving with minimal steel.

It should also be noted that although steel fiber reinforced concrete has excellent toughness and durability against impact-related damage, it is not particularly resistant to sand related abrasion loss of concrete. Moreover, use of short steel fibers should not be considered to provide adequate structural reinforcement in lieu of deformed bars or wire mesh.

Additional information on the design and application of shotcrete and gunite is provided in appendix B, section 11.

PROCEDURES

There are several procedures and guidelines that may be used for paving the inverts of metal and concrete culverts. These procedures can be used equally well for both metal and reinforced concrete, with certain modifications.

1. The following guidelines have been abstracted from the National Corrugated Steel Pipe Association's *Drainage Technology Bulletin* on "Rehabilitation of Corrugated Steel Pipe and Pipe Lines of Other Materials" dated September, 1988(3).

    a. The bottom 25 percent of the inside circumference for round pipe, the bottom 30 percent of the inside periphery for pipe-arch spans of 10 feet 3 inches and shorter and the bottom 35 percent of the inside periphery for pipe-arch spans longer than 10 feet 3 inches shall be paved unless otherwise specified by the engineer. Details of this procedure are shown in figure B.29.1.

    b. The minimum coverage over corrugations shall be 4 inches.

    c. The contractor shall schedule and conduct his diversion of water operations prior to and during the placement of pavement in a manner satisfactory to the engineer;

    d. When pavement is placed, the surfaces to be in contact with concrete shall be clean and dry to the satisfaction of the engineer.

    e. The pavement shall be reinforced with steel fabric reinforcement meeting the specification requirements of Federal Specification FP-85, Section 709 - Reinforcing Steel and Wire Rope. The reinforcement shall be placed two inches above the crests of corrugations and securely fastened by welding or tying to studs or angles previously welded to the structure. Studs or angles are to be spaced two feet on center longitudinally and transversely. The reinforcement shall be placed to provide a four-inch minimum clearance from the edges of concrete and shall be lapped six inches minimum. Unless otherwise shown on the plans, the steel fabric reinforcement shall consist of No. 6 gauge wire at six inch centers transversely and longitudinally.

    f. The pavement shall be finished to a smooth surface acceptable to the engineer. Within 18 hours after completion of finishing, the surface shall be protected by either an approved curing cover or an approved membrane curing compound applied at a minimum rate of one gallon per 150 square feet. However, any concrete in the invert that would be exposed to sunlight shall be protected by one of the above methods immediately after finishing operations have been completed and the surface water has evaporated.

g. The concrete shall cure for a minimum period of 48 hours before water is permitted to flow on the invert.

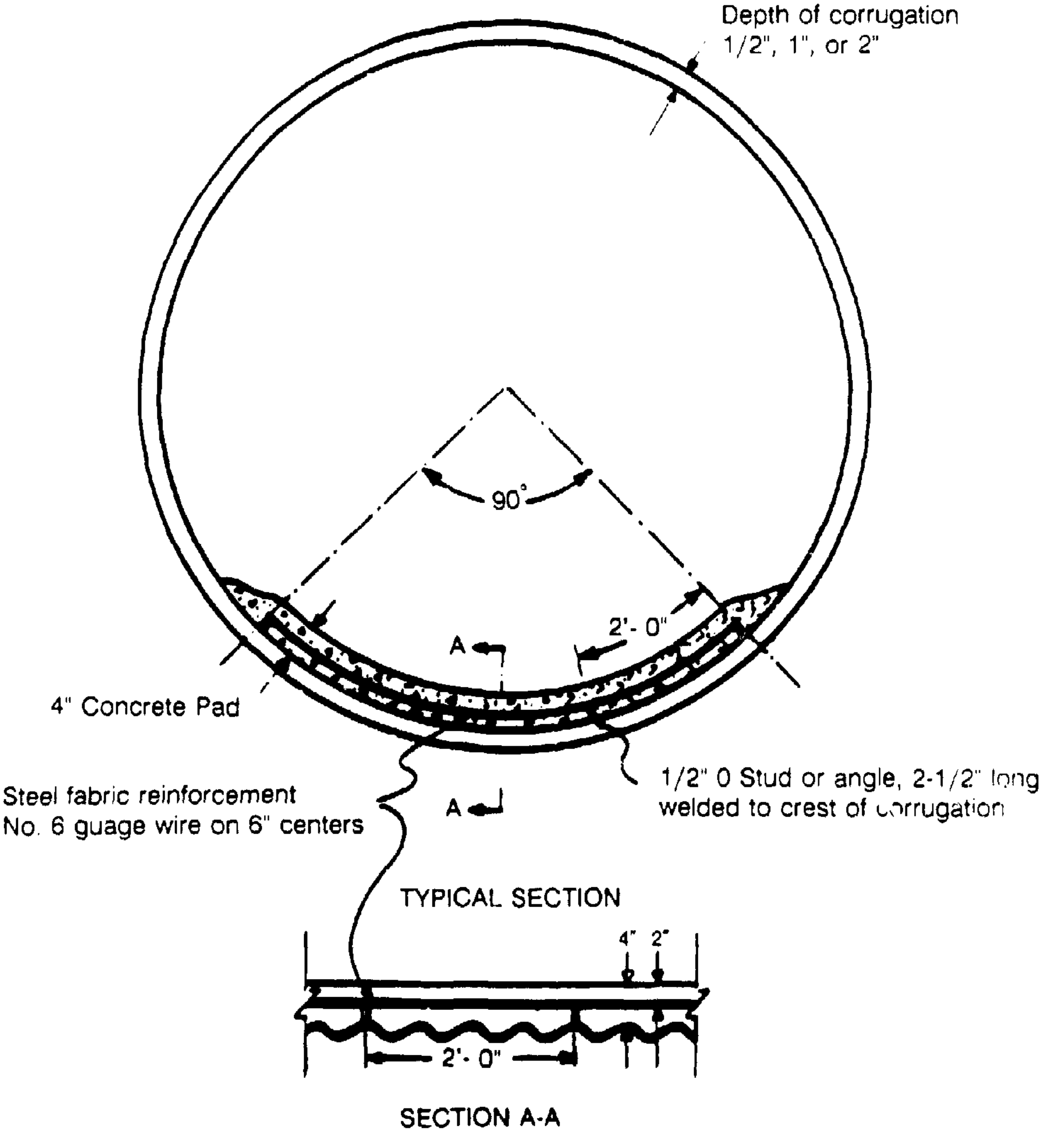


Figure B.29.1 Reinforced concrete invert paving for corrugated steel pipe.(3)

2. The following is an alternate specification (to the above) for in-place installation of a concrete invert. It covers two Ohio Department of Transportation projects that were undertaken in 1988. These guidelines have been abstracted from the National Steel Pipe Association's Drainage Technology Bulletin on "Rehabilitation of Corrugated Steel Pipe and Pipe Lines of Other Materials" dated September, 1988. Details of this procedure are shown in figures B.29.2 and B.29.3.

ITEM: SPECIAL SURFACE PREPARATION OF CULVERT INVERT
This item shall consist of preparing the culvert by removing all debris, dirt, and any other material that might be present.

This item shall also include tack welding of all wire reinforcing mesh to the corrugations of the pipe. This tack welding shall be performed as shown on the plans and as directed by the engineer to hold the mesh in place during pouring of the concrete.

ITEM: 503 COFFERDAMS, CRIBS AND SHEETING
This item shall consist of furnishing all labor, material and equipment necessary to dewater the culverts for the performance of this work. All other drainage flow shall be maintained at all times while the work to the pertinent culvert is in progress. All materials and devices placed in the stream to regulate or divert flow shall be removed at the conclusion of the work.

ITEM: 602 CONCRETE MASONRY INVERT REPAIR, AS PER PLAN
This item shall consist of all labor, material and equipment necessary to fill all voids found to be present below the bottom of the existing steel pipe.

These areas shall be filled with Class C Concrete (using the following mixture) up to the bottom of the pipe. Note: The maximum size of coarse aggregate is to be #8 limestone.

Fine Aggregate	1440 lbs
Coarse Aggregate (#8 Max. Stone)	1410 lbs
Total Aggregate/cu.yd.	2850 lbs
Cement	600 lbs
Water/cement ratio (maximum)	0.5

Note: Position the wire mesh (6x6x8x8) so that the transverse wires lie in the grooves of the multi-plate type corrugated sheets. Tack weld wire mesh to invert every 30" longitudinally and every 2" transversely as shown.

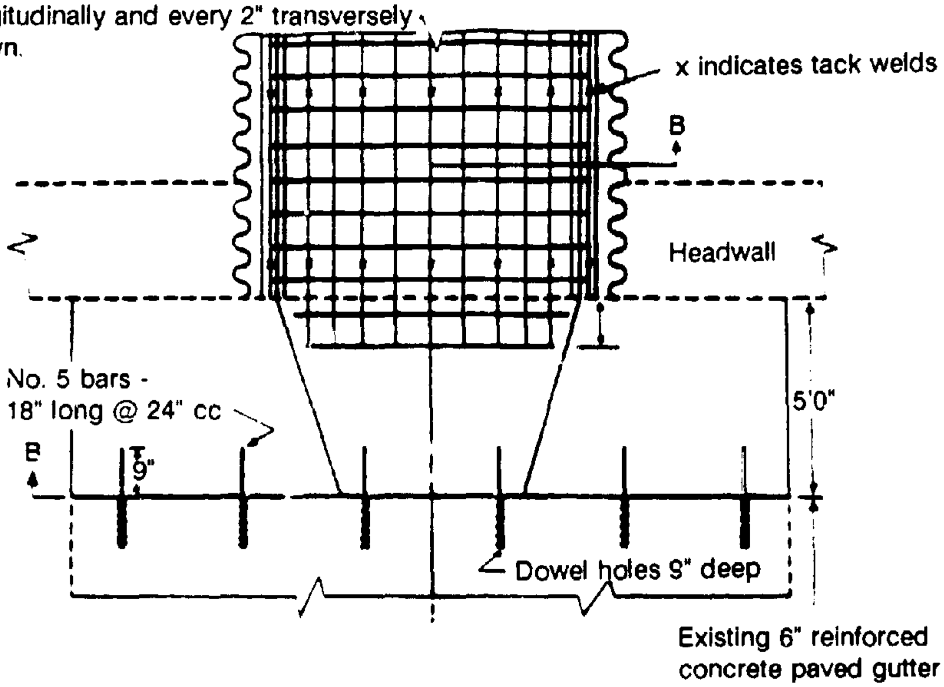


Figure B.29.2. Reinforcing plan for invert paving.[3]

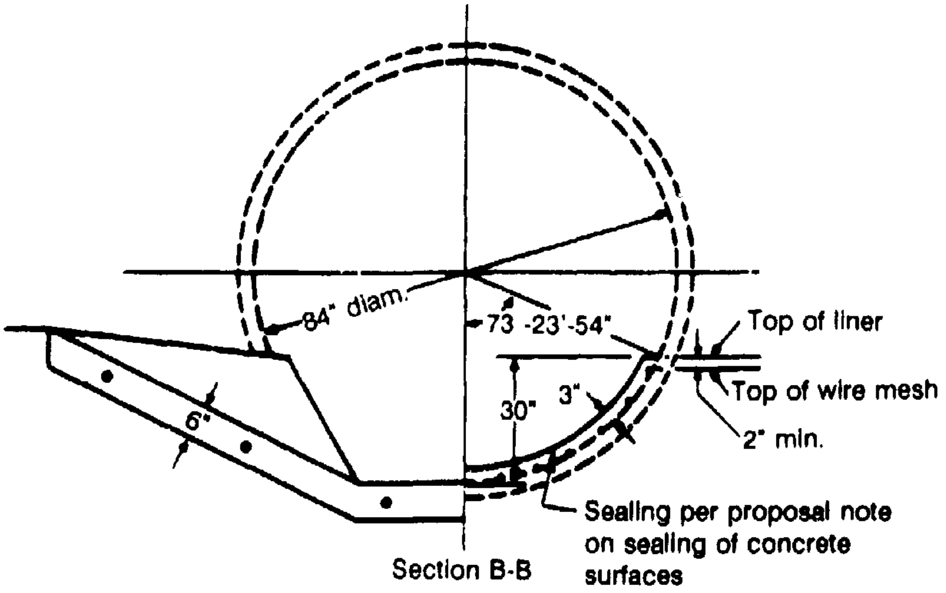


Figure B.29.3. Cross section for Ohio invert paving.[3]

This item shall also include removal of any unsuitable material in these void areas, as directed by the engineer. These void areas shall be filled with concrete prior to placing the concrete invert paving. Portions of the culvert plates should be removed as necessary to facilitate complete filling of the voids.

The quantity shown on this item is an estimated amount. The actual quantity placed will be determined by the engineer.

ITEM: 602 CONCRETE MASONRY, INVERT PAVING, AS PER PLAN

This item shall consist of furnishing and placing the concrete invert paving as shown on the plans. The contractor shall have the option of placing this concrete in a conventional manner using the mix specified above for invert repair or using pneumatically-placed mortar. In either case, the surface of the invert paving shall conform to the radius of the existing pipe as shown on the plans. The concrete shall conform to the radius of the existing pipe as shown on the plans. The concrete shall be finished as per section 511.17 (not included herein).

If pneumatically placed mortar is used, the work shall be performed in accordance with the requirements of item 502 (not included herein) in construction and materials specifications book except the wire mesh as shown on the plans will be used in lieu of wire fabric.

This item shall also include the additional material and labor to construct six-inch reinforced concrete paved apron at the pipe inlet.

The apron, as shown, transitions the circular invert paving to the existing six-inch reinforced concrete riprap and is butted and doweled into the existing said riprap at the inlet end.

The wire mesh and reinforcing steel furnished and placed as shown on the plans are also included in the unit price bid for this item.

ITEM: SPECIAL SEALING CONCRETE SURFACES

The surface of the Class C concrete invert paving shall be treated with material specified in the proposal note.

All of these methods described previously herein require a complete inspection and evaluation of the existing pipe to determine the best choice. With CSP (corrugated steel pipe), rehabilitation often requires merely providing a new wear surface in the invert. Typically, structural repair is unnecessary. However, if the pipe is structurally deficient, this does not rule out rehabilitation. Repair methods can be utilized and the structures restored to structural adequacy and then normal rehabilitation procedures performed. Even with 25% metal loss, which occurs long after perforation, structural factors of safety are reduced only 25%. When originally built, CSP storm sewers often provide factors of safety of 4 to 8, far in excess of that required for prudent design.

3. The US Army, Corps of Engineers used the following specification (in 1973) to restore the invert of a three-cell reinforced concrete box culvert that had a severe abrasion problem and loss of concrete due to rocks and other debris that passed through the culvert. This procedure involves paving the invert with steel fiber reinforced concrete. The restored invert has functioned in a satisfactory manner for 18 years, with little damage due to abrasion.

   Steel Fibrous Reinforced Concrete. A steel fibrous concrete overlay, 1-1/2 inch minimum thickness, shall be applied to the invert of the existing culvert, to level and recondition the existing surface. The fibrous concrete shall be composed of 3/8-inch coarse aggregate (pea gravel), fine aggregate, portland cement, wire fibers, water and admixtures as directed. The fibrous concrete shall be batched, charged, mixed, transported, placed and cured as directed by the Contracting Officer's representative. The Contractor shall perform a full scale trial batching, charging and mixing test, one cubic yard in size, to determine the proper proportioning rates for the steel fiber. Quality control tests and test specimens shall be made from the trial batch material. No separate payment will be made for the proportioning, batching, charging and mixing the trial batch, however, the Government may elect to cast test specimens of the wasted fibrous concrete. Truck mixers shall not be batched over approximately 50 percent of their rated capacity or 3 cubic yards, whichever is smaller. Except as modified herein and below, fibrous concrete shall be batched and mixed in accordance with ASTM C94.

   a. The fine and coarse aggregates shall be weighed in the usual manner.

   b. When all the aggregates are in the mixer, approximately 80 percent of the mixing water shall be added to the rotating mixer.

   c. The steel fibers shall be added to the fine and coarse aggregate and water mixture at the mixer at a near continuous rate. The wire shall be passed through a 2-1/2 to 3-inch vibrating screen; either by hand dumping from boxes or by batching through a hopper in such a manner that clumps of fibers are not introduced into the mix.

   d. All the cement shall be batched and charged into the mixer.

e. Remaining water shall be added prior to transporting to the job site.

f. The fibrous concrete mixture shall pass through a 2-inch screen prior to entering the conveying vehicle for the placement.

Fiber Reinforcement. The contractor shall furnish ferrous wire reinforcing fibers of either round, flat or deformed section. The fibers shall have one of the following dimensions:

	Section Inch		Length Inch
Round	0.016	x	1
Flat	0.01 x 0.020	x	1
	0.01 x 0.022	x	1
Deformed	0.016 round		
	0.010 x 0.020	x	1

The wire fibers shall have a minimum tensile strength of approximately 90,000 psi and may be brass plated. The wire fibers shall be proportioned at approximately 220 pounds per cubic yard. Separate payment will be made for wire reinforcing fibers used in the repair work.

Cleaning and Concrete Removal.
The Contractor shall clean the entire interior surface (to be repaired) with either high-pressure water jet and/or wet sandblasting in accordance with the requirements specified herein.

Drilling and Grouting Anchor Bars. The new fibrous concrete shall be anchored to the existing structure by means of steel reinforcing bars installed in locations and as shown on the drawings. These bars shall be straight and hooked on one end and shall be fabricated as indicated on the drawings. Anchor bars shall be placed to extend to depths as indicated on the drawings. The diameter of each anchor bar hole shall be not less than 1-1/2 times the diameter or greatest transverse dimension of the anchor bar specified for that hole. Holes for anchor bars shall be drilled at the angles shown on the drawings. Bars shall be of proper length so that the outer ends will have the coverage of concrete shown on the drawings. Drill holes shall be cleaned with compressed air immediately before the bars are grouted. Anchor bars shall be cleaned of all traces of sludge, oil, rust, or other objectionable matter before grouting is accomplished. The holes shall be filled with plain grout, following which the bars shall be forced into place and vibrated or rapped until the entire surface of the embedded portion is in intimate contact with the grout. Subsequent movement of the bars shall be prevented, and any bars found to be loose after the grout has set shall be properly reset at the expense of the Contractor. Bars shall be grouted at least 36 hours prior to placing the fibrous concrete.

4. An alternate to the above, for culvert inverts that are subject to severe abrasion damage is to pave them with high strength concrete. It has been found that the toughness of Portland Cement concrete is proportional to the compressive strength. The State of Colorado has had good success with paving inverts with concrete that has a 28-day compressive strength in the range of 8,000 psi. Guidelines for the design, production and use of high strength concrete have been developed by ACI Committee 363 on High Strength Concrete.

5. For culverts that are located in areas that have acidic water passing through them it may be necessary to protect the concrete surface against acid attack. At least one State highway agency coats the surface with a polymer type material, such as an epoxy sealer or a polymer concrete (a mixture of a resin and sand). Such materials are routinely used by many highway agencies to protect bridge decks and structural concrete against corrosion due to deicing or seawater salt. It should be noted that the concrete surface must be dry for application of most of these materials.

Gunite Repair and Paving of a Corrugated Metal Pipe Arch Culvert in Maryland

Objective: Strengthen corrugated structural plate pipe arch culvert

Procedure: Install sandbag check dam and plastic pipe to channel drainage water through the culvert. Dewater 2-ft-deep hole under 15 to 20 feet of corroded out invert. Install steel reinforcing bars across invert and attach them (by welding) to the existing metal culvert, at just below the springline of the arch. Fill the hole below the invert with gunite (dry-mix), to just below the reinforcing bars. Apply gunite to pave the invert.

Figure B.29.4 Existing corrugated structural plate pipe arch culvert. Survey rod shows 2-foot deep hole under missing invert.

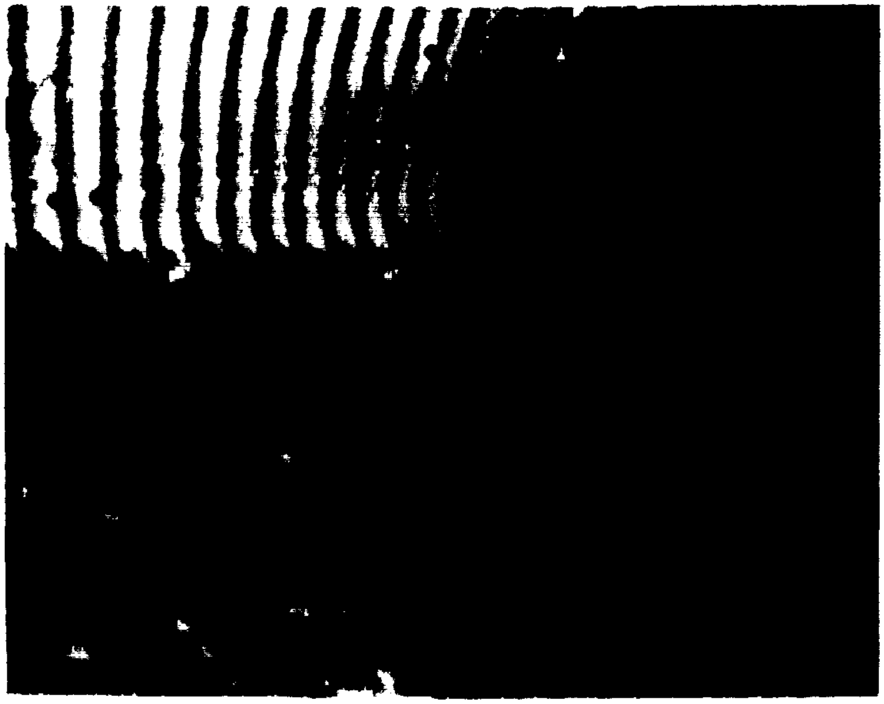


Figure B.29.5 Reinforcing bars installed across invert.

Figure B.29.6 Paving of invert with (dry-mix) gunite.

Figure B.29.7 View of rehabilitated culvert, showing smooth paved invert.

RESOURCE COMMITMENT = 3:	5 Heavy	4	3 Medium	2	1 Low
COST RELATIVE TO REPLACEMENT = 2:	5 High	4	3 Medium	2	1 Low

REFERENCES

1. "Guide for Specifying, Mixing, Placing, and Finishing Steel Fiber Reinforced Concrete," (ACI 544.3R-84/88), *ACI Manual of Concrete Practice*, American Concrete Institute, 1989.

2. "Guide of the Use of Polymers in Concrete," (ACI 548.1R-86), *ACI Manual of Concrete Practice*, American Concrete Institute, 1989.

3. "Rehabilitation of Corrugated Steel Pipe and Pipe Lines of Other Materials," *Drainage Technology Bulletin*, National Corrugated Steel Pipe Association, September 1988.

4. "Specification for Materials, Proportioning, and Application of Shotcrete." (ACI 506.2-77/83), *ACI Manual of Concrete Practice*, American Concrete Institute, 1989.

5. "State-of-the-Art Report on Fiber Reinforced Concrete," (ACI 544.1R-82/86), *ACI Manual of Concrete Practice*, American Concrete Institute, 1989.

6. "State-of-the-Art Report on Fiber Reinforced Shotcrete." (ACI 506.1R-84), *ACI Manual of Concrete Practice*, American Concrete Institute, 1984.

7. "State-of-the-Art Report on High-Strength Concrete," (ACI 363R-84), *ACI Manual of Concrete Practice*, American Concrete Institute, 1989.

APPENDIX B-30. PROCEDURES FOR GROUTING VOIDS BEHIND AND UNDER CULVERTS

APPLICATIONS

The following discussion deals with the materials and procedures that may be used to grout voids behind and under culverts.

COMMENTS

During the 1980's there have been substantial advances in the development of grouts and grouting techniques. Much of this advancement is the result of the need for improved techniques for grouting underground construction, machinery bases, and segmental prestressed concrete and cable-stayed bridges. It has been well established that the primary objective of grouting is to completely fill the required space with a material that will not shrink segregate, or otherwise create additional problems.

Critical reviews of previous grouting jobs have led to the development and use of special admixtures for Portland cement based grouts and mortars, and chemical and foaming grouts that foam and expand when they come in contact with water. In general, for culvert repair work Portland cement based grouts, with and without special admixtures, are adequate and much less expensive than the foaming and chemical grouts that are used to set machinery and to resist high external and internal fluid pressures.

The primary objective of completely filling the void can be accomplished by adequately studying site conditions and properly planning and executing the grouting operation. The principal problem to be avoided in entrapment of air or water in the void to be filled with grout. The procedure to be used for grouting must recognize this potential problem and provision must be made for air or water to be vented out of the void as grout is pumped into the void. Depending on the location of the void to be filled, the grout may be installed with a pressure pumping system or it may merely flow in by gravity.

Normally voids under corroded or undermined inverts may be filled by a gravity-flow method. Voids behind the sides of culverts that are caused by piping or exfiltration will have to be pressure grouted to ensure that the void is properly filled. However, for certain situations where the void can be accurately located, it may be possible to fill side voids by gravity feed from the roadway surface.

PROCEDURES

There are basically three procedures for grouting:

1. Gravity Flow from Above the Void
   This concept involves merely pouring the grout into the void from above it. It is assumed that the fluid grout will completely fill the void without entrapping air and that any water in the void will be displaced as the heavier-than-water grout displaces it.

   Although this technique may work for a water-filled void, the grout will probably be dispersed in the water with the result that the void will not be properly grouted. It is much preferred that any water in the void be pumped out prior to grouting.

2. Grouting Through a Tremie Pipe or Tube
   For this gravity feed concept the grout is introduced into the void by pouring it into a tremie tube, so that grout fills the void from the bottom with an upward flow of the grout. The procedure may be warranted for some site conditions where there is a potential problem of entrapment of air in the grout.

3. Pressure Grouting
   This concept will normally be used to fill voids behind the sides of culverts. If the void is behind an open joint, it will be necessary to seal the interior surface of the joint, normally with a concrete mortar, or a joint sealing system, such as those described in appendix B, section 25.

   The most effective procedure for grouting will then involve installation of grout tubes at the bottom and the top of the joint or void. The grout is then pumped into the lower tube. Air or water will, at first, flow out of the upper tube, then a watery grout will flow out, and finally a pure grout will flow out of the upper tube. At this point it may be considered that the void is properly filled.

PRECAUTIONS

1. The grouting procedures should be designed so that air or water is not trapped in the void.

2. The grouting pressure should be monitored to prevent bursting of lines and/or displacement of the culvert walls if a blockage develops in the grout lines.

RESOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. *"A Professional's Handbook on Grouting Concrete Repair and Waterproofing,"* Five Star Products, Inc.

2. *"How to Grout,"* L & M Construction Chemicals, Inc., 14851 Calhoun Rd., Omaha, Nebraska 68152.

3. "Grouting Slip Liners: The New Inside Story," by L. Lee, *Civil Engineering*, September 1990.

4. 3M Company, Contractor Products Department, St. Paul, Minnesota.

APPENDIX B-31. PROCEDURES FOR CATHODICALLY PROTECTING METAL CULVERTS

APPLICATIONS

Cathodic protection (CP) may be applied to all types of culverts that are made of or reinforced with metals. It will be most effective for steel culverts of all types.

COMMENTS

Over the past few years some field research has been conducted to evaluate the corrosion susceptibility of buried steel culverts.(1,2) The results of these studies and serviceability records of highway agencies have shown that one of the most serious fundamental problems that can occur with corrugated steel pipe and pipe arch culverts is corrosion, due to chemicals in the surrounding soil and in the water that passes through the culvert. The Louisiana research study verified that most underground metal culverts experienced severe attack in low resistivity soils after an exposure time of ten years or less.(2)

The concept of using cathodic protection (CP) techniques to protect metal culverts is a logical extension of extensive research and the current practice to protect buried and above ground pipelines in this manner.(3 to 7) For some installations it is necessary to cathodically protect both the inside and the outside of pipelines. The study by Simpson and Robinson examined the use of CP with various types of coatings on steel pipelines. They reported that the best coatings to use with CP were epoxy and coal tar epoxy coatings.(7)

The Louisiana Department of Transportation is currently funding a research study to assess the feasibility of applying cathodic protection to both the inside and the outside of metallic culverts to prevent corrosion from occurring. The study includes evaluation of the benefits of applying CP to eight different types of corrugated metal culverts with various types of coatings. Following the conduct of laboratory tests, field tests are being conducted on eight ten-foot sections of 24 in diameter corrugated metal pipe. The CP system is of the passive sacrificial anode type. "The interim results (after 2.5 years) have proved that culverts can be economically protected from corrosion using CP. It has been found that the outside of the culvert requires significantly more current for protection than does the inside. All of the unprotected culverts are experiencing corrosion, and the culvert requiring the least amount of current is the polymeric coated galvanized steel. It is recommended that CP be applied to culvert systems that are in low resistivity environments. Culverts being installed in new locations should be electrically connected so that CP can be more easily applied later."(8)

PROCEDURES:

Although it may be possible to install a passive cathodic protection system in a variety of ways, the following are the procedures that were used for the above-cited Louisiana DOT funded research study.

1. After lowering the corrugated steel pipe into the ditch, as shown in figure B.31.1, zinc anodes were installed along the invert of the culvert sections, and connected by wiring that was attached to the culverts and their connecting bands. The anodes were placed on rubber mats so that they would be electrically insulated from direct contact with the culvert.

2. External zinc bar anodes were pushed into the ground alongside, but not touching, the culverts. They were pushed into the ground with construction equipment, as shown in figure B.31.2. The zinc bars were connected to the culvert by wiring.

Detailed information on the procedures and materials used for this project may be obtained by contacting Dr. James Garber, the research Principal Investigator, at the University of Southwestern Louisiana, in Lafayette, Louisiana.

Figure B.31.1. The unprotected corrugated steel pipe is lowered into the ditch.[8]

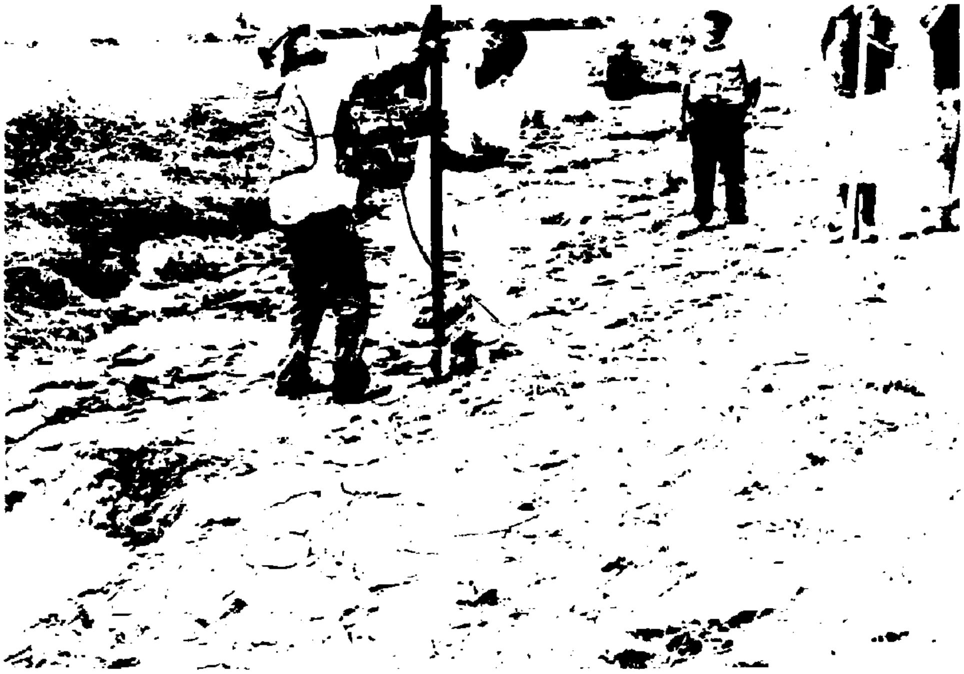


Figure B.31.2 Installation of external zinc anode bars.[8]

RESOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = *:	5	4	3	2	1
	High		Medium	Low	

* Varies according to type of CP system used.

REFERENCES

1. *Condition and Corrosion Survey on Corrugated Steel Storm Sewer and Culvert Pipe - Second Interim Report*, The National Corrugated Steel Pipe Institute, 1988.

2. W. H. Temple, S. L. Cumbaa, B. J. Gueho, *Evaluation of Drainage Pipe by Field Experimentation and Supplemental Laboratory Experimentation*, Report FHWA/LA-85/174, Louisiana Transportation Research Center, Lafayette, Louisiana, March 1985.

3. *Control of External Corrosion on Underground or Submerged Metallic Piping Systems*, Standard RP-01-69, National Association of Corrosion Engineers (NACE), Houston, Texas

4. F. Q. Jensen and R. D. Tems, *Internal Cathodic Protection of Cement-Lined Steel Pipes*, NACE Corrosion 88, Paper 25, St. Louis, Missouri, 1988.

5. R. E. Groover and M. H. Peterson, "Cathodic Protection of Internal Surfaces of Pipes Containing Sea Water," *Materials Performance*, November 1984.

6. W. B. MacKay and L. R. Grace, *Cathodic Protection of Pipeline Internals*, Proceedings of the 4th International Congress on Marine Corrosion and Fouling, Antibes, 1976.

7. V. P. Simpson and R. C. Robinson, *Experimental Studies Relate Effect of Cathodic Protection with Certain Generic Coating systems*, Offshore Technology Conference, 1980.

8. J. D. Garber, J. H. Lin and L. G. Smith, *Feasibility of Applying Cathodic Protection to Underground Culverts (Interim Report)*, Report FHWA/LA-91/238, Louisiana Department of Transportation & Development, Baton Rouge, Louisiana, June 1991.

APPENDIX B-32. PROCEDURES FOR STEEL ARMOR PLATING AND REINFORCING INVERTS

APPLICATIONS

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.

COMMENTS

For some locations in hilly or mountainous country, paving of culvert inverts with conventional or even special concrete will not provide adequate protection against abrasion and impact damage. Several highway agencies have found that it is necessary to armor the inverts with steel plates. In some cases such armor plating has solved the problem while in others the plates were worn down after a period of time. Thus, some attention must be given to design of the armor plating system and selection of plates that have sufficient thickness to withstand years of abrasion.

PROCEDURES

There are several possible ways in which the inverts of culverts may be armored with steel plates. The following describes two methods that have been used by highway agencies.

1. In 1952, the Alabama highway department constructed a triple line of 84 inch diameter corrugated structural plate culverts in Cullman County. The 517 foot long culverts are under a 135 foot deep roadway fill. The culverts were subjected to severe abrasion due to sandstone that was carried through the culvert by high velocity water that operated under headwater depths of 40 feet or greater. In 1973, the State let a contract to repair the deteriorated inverts with steel armor plating.

   The contract specified the installation of shaped 3/8 inch steel plate in the existing culverts. Steel (KSM or Nelson) anchor studs were attached to the invert armor plate and to the existing invert and embedded in a concrete mortar to bond the pipe and the armor plate together, as shown in figure B.32.1. The length of the armor plate sections and handling procedures were left to the contractor's discretion.

   The initial phase of work was to construct a diversion dam to block water from one and into the remaining two pipes. After dewatering, groundwater entering through cracks in the pipe walls was halted with a quick-setting cement seal.

The next construction step consisted of attaching an overhead monorail system to the crown of the culvert pipes for transporting the steel armor plates. The plates were 90-3/4 x 98 x 3/8 inch and weighed 945 pounds, preshaped and fitted with the required number of anchor studs. Details of the monorail and the armor plates are shown in figure B.32.2.

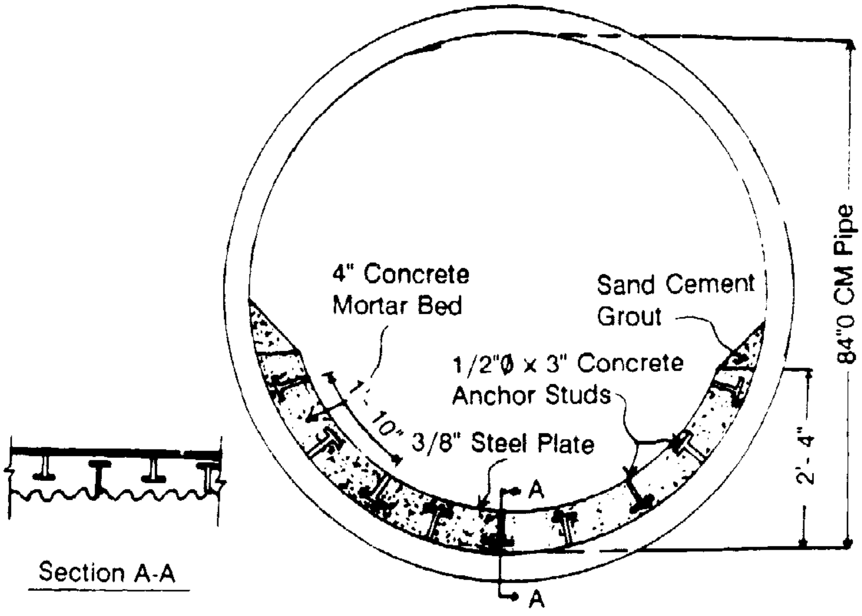


Figure B.32.1. Armor plate typical section.(1)

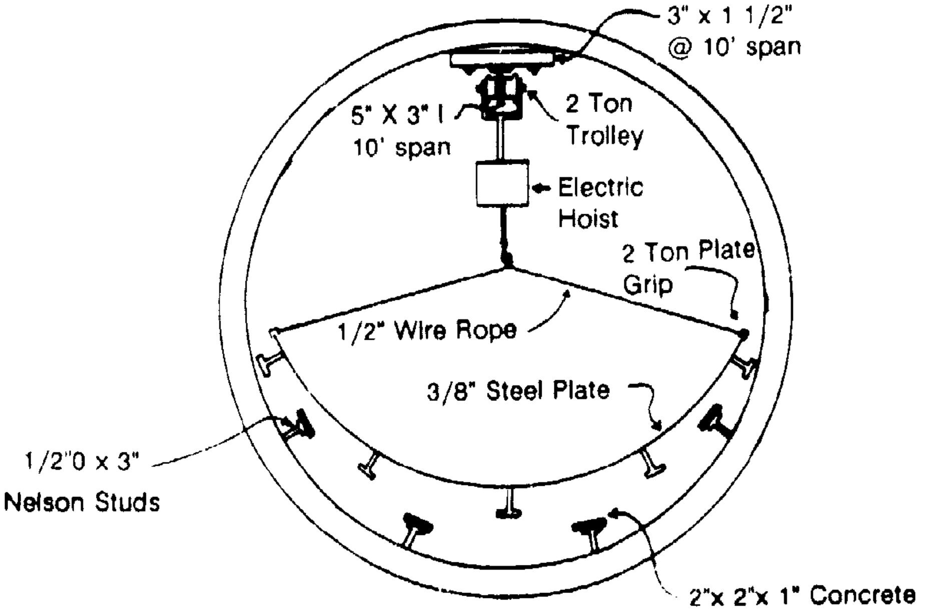


Figure B.32.2. Method of installation.(1)

After all water was removed from the culvert, anchor studs were welded to the invert of the existing culvert. Concrete spacer blocks were then attached to the heads of the studs in the invert with an epoxy adhesive.

Initially the next step was to place the concrete mortar bed and to lower the steel armor plates into it. This procedure was found to be unsatisfactory because vibration of the plates and the mortar to remove voids in the mortar caused movement of the plates and problems with their alignment.

The procedure was modified so that a group of three plates was set, tack-welded together and braced before placement of the concrete. The concrete bedding was then placed and vibrated to remove air voids.

After allowing the concrete to cure for seven days the braces were removed and the plates were welded together. Gaps between the plates, which were caused by variations in alignment and profile, were closed by welding on strips of armor plate.

The edges of the unfinished concrete were then coated with an epoxy and a sand-cement grout was applied to provide a uniform finish.

The contractor was required to regalvanize damaged areas of the crown after removal of the monorail system.

Inspection of the culvert after nine years of service indicated satisfactory performance, with no adverse wear. Armor plating the inverts of the triple-line culvert was accomplished at a small fraction of the possible cost for replacement of the culvert.

Additional information on this project is provided in Reference No. 2, below.

2. In the early 1970's the Colorado highway department had severe rock abrasion problems with a ten year old 1500-foot long reinforced concrete box culvert under a large interstate highway intersection, near Golden, Colorado. The approach streambed was steep and large and medium size boulders were carried by stormwater and snowmelt. The culvert was constructed on fairly steep grade and the inlet walls and invert narrowed from 20 foot square to 10 foot square while dropping approximately 8 foot, to ensure a high velocity flow that would keep rock and sediment from building up inside of the culvert. The highway department had tried many methods of reinforcing the concrete against abrasion, with little success, since construction of the culvert in the 1960's.

The final solution was to "pave" the approach and a portion of the invert inside of the culvert with 2-inch-thick steel plates, as follows:

a. The curved descending invert of the box culvert was first paved with concrete to the desired shape.

b. Two-inch-thick steel plates were then positioned across the invert.

c. Holes were then drilled (through holes in the plates) through the underlaying concrete and then into bedrock.

d. The plates were then anchored to bedrock with bolts that were set into an epoxy resin.

Details of this installation are shown in figures B.32.3 and B.32.4. It may be seen from figure B.32.4 that some wear of the steel plates has occurred over the past 20 years.

3. For corrugated steel culverts, some highway agencies have installed a double thickness of multiplate sections in the invert or have installed multiplate sections in the invert of circular and arch culverts. This must be securely fastened to the primary culvert to prevent movement and deterioration of the underlaying plate materials.

4. The Oregon highway department has reinforced the inverts of reinforced concrete box culverts with steel grid bridge decking and old railroad rails, to protect the inverts from impact and abrasion damage. The inverts of culverts that have been reinforced in this manner have performed very well, since they were installed about six years ago.

Steel Plate Armoring of Invert of Concrete Box Culvert in Golden, Colorado

Figure B.32.3. Tapered and narrowing inlet to 10-foot-square box culvert.

Figure B.32.4. Approach and invert armored with 2 in-thick steel plates.

RESOURCE COMMITMENT = 3:	5	4	3	2	1
	Heavy		Medium		Low

COST RELATIVE TO REPLACEMENT = 2:	5	4	3	2	1
	High		Medium	Low	

REFERENCES

1. Stephen R. Ikerd, "Invert Replacement of Corrugated Metal Structural Plate Pipe," *Symposium on Durability of Culverts and Storm Drains*, Transportation Research Record No. 1001, Transportation Research Board, Washington, D.C., 1984.

2. *Handbook of Steel Drainage & Highway Construction Products*, American Iron and Steel Institute, Washington, D.C., 1983.

APPENDIX B-33: PROCEDURES FOR MEASURING AND EVALUATING CULVERT DISTORTION

APPLICATIONS

The following techniques may be used to measure, monitor, and evaluate distortion of culverts, and other types of structures.

COMMENTS

Highway culverts, as with any other type of structure, are never built in perfect accordance with the plans, or perfectly symmetrically. Moreover, corrugated metal culverts are considered to be flexible structures by the nature of their construction materials as well as their close interaction with pressures applied by the supporting soils and highway vehicle loads. It is well established that corrugated metal culverts will bend and change their shape during their construction, because of uneven compaction of the supporting soil. Because of creep-type redistribution of forces in the soil, such structures may deform and otherwise seek a position of equilibrium for some time after construction is completed. During the service life of a culvert, the support provided by the surrounding soil may also change, due to environmental conditions, erosion at the ends of the culvert, and problems due to infiltration, exfiltration and piping. Thus, the shape of a corrugated metal culvert may not be symmetrical for either the entire length or the culvert or individual sections of it.

With regard to the above, it is important to determine whether the culvert is stable in its distorted shape or whether it is continuing to become distorted, and if it is, the rate at which it is distorting. It is quite common to have at least some symmetrical or unsymmetrical distortion in corrugated metal culverts. It is also common that the culvert is stable in that distorted shape; that is, it is not continuing to distort. If this is the case, then corrective action is not nocessary. On the other hand, if it is distorting, determination of the rate of distortion will give the agency an idea of how rapidly corrective action may be necessary.

The following are techniques that may be used to measure the interior shape or a culvert. If they are used twice or more, it is possible to determine whether their shape is changing and at what rate.

It is extremely important that well identifiable and permanent locations be chosen as measurement points, and their location must be carefully documented, so that they may be repeatedly used over a long period of time. It is safest to use joints, seams, or bolts that may be easily identified in the future. For critical locations it may be a good practice to use more points than the minimum number necessary so that if one or more points are lost, the entire section will not be lost. The number of measurement points that are used will depend upon the size and condition of the culvert.

PROCEDURES

1. Conventional Survey Techniques

Many highway agencies use traditional survey equipment and techniques to measure the shape of a culvert. The advantages and disadvantages of this approach are:

Advantages:

- The equipment is available and State and contractor personnel are proficient in using it; and
- It is relatively inexpensive to use.

Disadvantages:

- It is time consuming and somewhat difficult to determine exact changes in shape;
- It is difficult to obtain measurements inside of a culvert, due to lighting conditions; and
- Work can be dangerous, particularly if the culvert has a considerable water flow.

2. "Total Station" Survey Techniques

An alternative to conventional surveying is to use the new electronic "total station" survey equipment. This type of system uses a new type of survey "transit" that has an electronic data storage adapter that is used to record all survey "readings." The survey procedure normally involves the instrument person sighting on a mirrored target. The instrument records the distance and angle to the target. The precision or accuracy of the readings is a function of the quality and features of the instrument. First-, second-, and third-order survey accuracy is available. Several State highway agencies routinely use such equipment, which is marketed by several companies. The following are advantages and disadvantages of this concept:

Advantages:

- The data pack from the survey instrument can be returned to the office, for "dump" and analysis of the data. The data can be transferred into a number of computer systems for analysis and plotting of cross sections of the culvert and determination of its shape at any cross section. Graphics packages can be used to plot three-dimensional views of the structure.

- Although an instrument person is needed for the first survey, that person may establish permanent targets by attaching mirror targets to the points of interest. Thereafter, the entire survey may be done by one person, the instrument person. (A second person should be present, for safety reasons if nothing else).
- This concept and equipment may be used to record survey data not only on the culvert but also its entrance and exit features from the beginning of construction.
- By starting the survey with the establishment of bench marks outside of the culvert, it is possible to determine not only whether the culvert shape is distorting but also whether the slope and elevation of the entire culvert is changing, although that may be unlikely.
- Procurement of such equipment for this purpose may help justify it for use on other critical types of surveys.

Disadvantages:

- The survey equipment cost is in the range of $8,000.
- The equipment may not be readily available to many district and residency-level offices of most highway agencies.

3. Photogrammetric Techniques

The Ontario Ministry of Transportation has developed a concept for measuring the shape of culverts that uses close-range photogrammetry equipment. The principles of close-range photogrammetry are similar to the traditional aerial photogrammetry, with three significant differences.

a. A very special 35mm camera is used, rather than the traditional large negative type camera used from aircraft.

b. Picture pairs may be taken from almost any vantage point on the ground.

c. Survey information is obtained by digitizing large size prints of the pictures, for example, 8 x 10 inch size prints.

Conduct of the survey is similar to the procedures described for "total station" type surveys; setup during the first survey involves setting mirror targets on the points of interest. Thereafter, surveys may be taken by a single person. Advantages and disadvantages of this concept are:

Advantages:

- The equipment is quite versatile.
- Data from the digitized photographs can be handled by computer, for analysis, plotting, and determination of changes in shape.
- The technique may be used for long culverts, with flowing water, by taking photographs from a raft floating through the culvert.

Disadvantages:

- The equipment is very expensive and somewhat fragile.
- The personnel needed must be very highly trained.

RESOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 2:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. Ontario Ministry of Transportation, Research and Development Branch, 1201 Wilson Avenue, Downsview, Ontario M3M 1J8. (Telephone. (416) 235-4674).

2. Leica Canada, Inc., 513 McNicoll Avenue, Willowdale, Ontario M2H 2C9. (Telephone: (416) 497-2460)

3. Leica, Inc., 2 Inverness Drive East, Suite 106-108, Englewood, Colorado 80112.

APPENDIX B-34. PROCEDURES FOR REPAIR AT A DISTORTED SECTION

APPLICATIONS

The following describes repair techniques that may be made at distorted sections of culverts. Although these deal mainly with corrugated metal type culverts these procedures may also be used for culverts made with other types of materials.

COMMENTS

Corrugated metal pipe and pipe arch as well as precast concrete culverts are subjected to a variety of external loads and changing soil conditions that may cause localized distortion and cracking after installation. It has been found that the uneven soil pressures that cause such distortion seldom stabilize and, in fact, related problems normally become worse. Total collapse is possible. If the distortion and cracking is an isolated condition in a culvert that is otherwise in fairly good condition, it may be possible to repair that section without disturbing the remaining section of the culvert. Although the following procedures will somewhat constrict the culvert opening, the influence of the reduction in the area will depend upon many site-specific details.

The amount and complexity of remedial action will depend upon the site conditions, the type of culvert, and the level and severity of the distortion. Site conditions include such factors as location, height of fill over the culvert, and whether infiltration is from water under a considerable hydraulic head pressure. The solution to the problem generally involves installation of an expansion ring that bridges and closes the open joint and pressure grouting to fill voids in the soil behind the joint. The closure ring may have to carry structural loads and external hydraulic pressure. The following describes several techniques and types of repairs that may be used. Information on grouts and grouting techniques is provided in appendix B, section 29.

PROCEDURES

1. <u>Strengthening With a Tunnel Liner Plate Ring</u>

   Several State and Canadian Government highway agencies routinely use tunnel liner plate to repair distorted culverts. Steel liner plates are curved and rigid. They are made with either two or four flanges that are used to bolt the sections together. If the culvert is only moderately deformed it may be practical to install and grout one or more complete rings of liner plate to strengthen the deformed section, by the following procedure.

   a. Install the bottom liner plates in the invert of the culvert by supporting the plate on steel chairs that are welded to the culvert and connecting them with anchor bolts. A gap of 6 to 8 inches should be provided, for grouting.

b. Grout the gap between the culvert invert and the bottom tunnel liner plate.

c. Symmetrically install additional tunnel liner plate to complete the ring. Bolt the top sections together.

Notes:

1. The liner plate should be provided with holes or pipe fittings in the shoulder areas, to facilitate grouting.

2. Stand-off bolt spacers should be installed in the crown sections, to prevent floating of the liner plate ring during the subsequent grouting.

d. Seal the outer edges of the liner plate ring, to prevent loss of grout.

e. Install grout, to completely fill the annular space between the liner plate ring and the existing culvert.

2. Replacement of Distorted Section with a Liner Plate Ring

If the isolated section of the culvert is severely distorted it may be necessary to remove and replace the distorted section by the following procedure, that is shown in figure B.34.1.

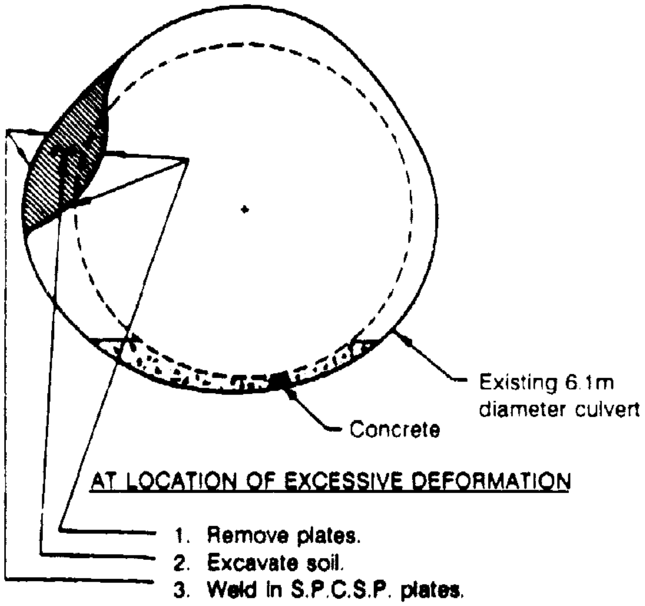


Figure B.34.1. Partial repair of deformed CSP pipe.[1]

a. Install two complete rings of tunnel liner plate on either side of the distorted section, as described in Procedure 1.

b. Remove the severely distorted section of culvert from between the two liner plate rings, **only after the grout between the culvert and the two rings has completely set and cured to the desired strength**.

c. Remove the excessive soil in the repair area to make room for a ring of liner plate.

d. Install a ring (or rings) of liner plate, as required, as described in Procedure 1. The replacement ring (or rings) should be connected to the two rings that were initially installed.

e. The area behind the replacement ring and the soil should be grouted, to provide uniform bearing and support for the liner plate ring.

3. <u>Complete Shotcrete Ring</u>

The Alberta (Canada) Ministry of Transportation has found that repair in the form of a complete ring may be necessary in cases where cracking and deformation is not confined to any particular location on the circumference. When a non-uniformly shaped culvert section that must be retained is to be repaired (See figure B.34.2), the most feasible repair method may be to shotcrete the complete ring. This method requires little preparation and it can be economically done, even in winter conditions. The thickness of the shotcrete ring (that they have used) is about 6 inches. Their procedure was to first pave the invert with 4,400 psi compressive strength concrete. The shotcrete that is used above the floor consists of a 9,400 psi compressive strength steel fiber reinforced mix without reinforcing bars. A silica fume admixture is used in the mix to reduce rebound losses. Additional information on shotcrete is provided in appendix B, section 11.

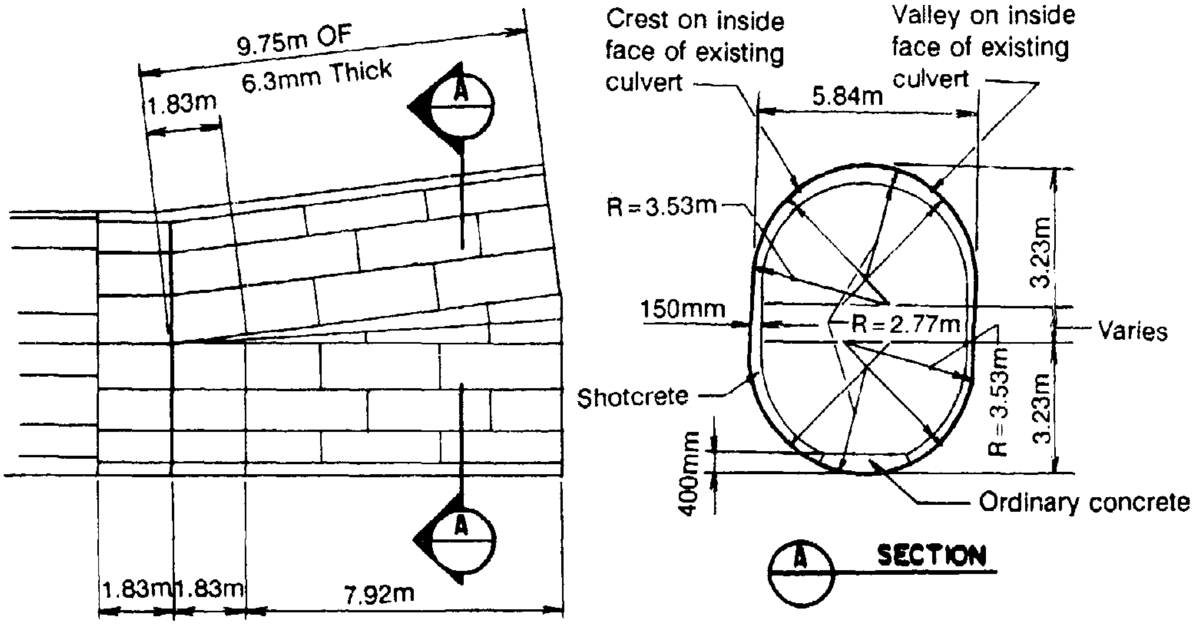
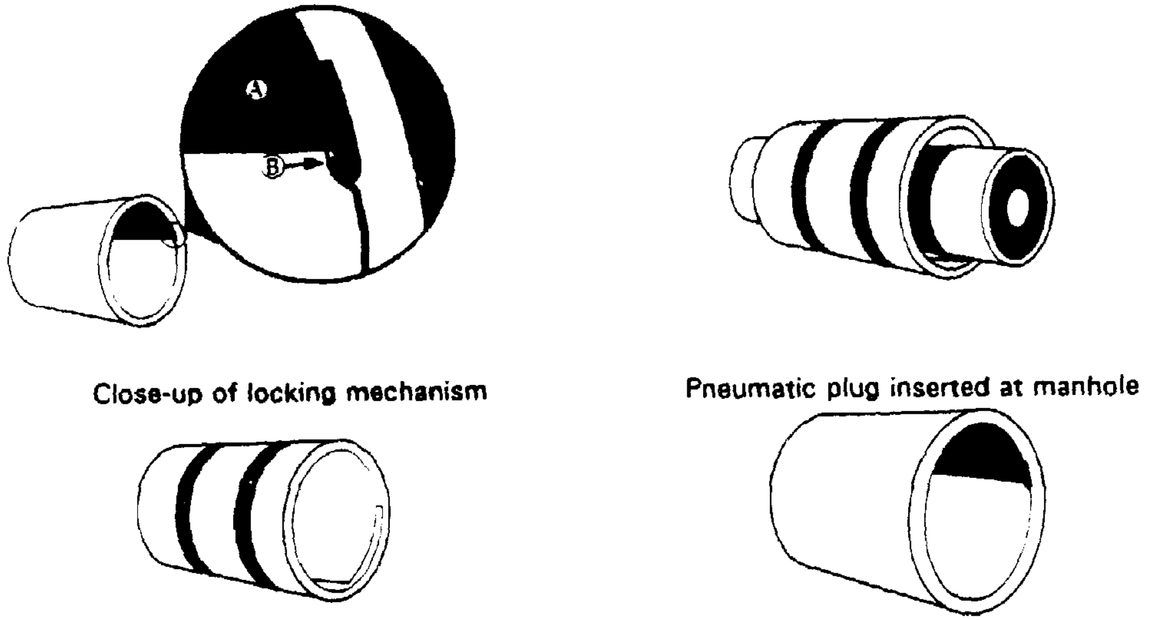


Figure B.34.2. Shotcrete ring in a distorted culvert.[1]

3. LINK-PIPE™ Stainless Steel Repair Sleeve

This system is designed to repair 6 inch to 24 inch pipelines by equipment that may be operated from outside of the line. (The system was formerly named "SNAP-LOCK™ Sewer Repair Sleeve") This type of liner sleeve is comprised of a sheet of stainless steel that is covered with a closed-cell polyethylene foam gasket that provides a tight seal against the interior of the existing culvert (or pipeline) section. One longitudinal edge of the stainless steel sheet is formed into a slot-type joint for the other edge to snap into during the installation process. Figure B.34.3 shows the two layers coiled into a smaller diameter and banded for insertion into a pipeline. Figure B.34.4 shows a cut-away drawing of the liner system and the installation equipment.



Close-up of locking mechanism

Pneumatic plug inserted at manhole

Coiled sleeve

Link-Pipe expansion completed

Figure B.34.3. Two layers coiled into a smaller diameter and banded for insertion into a pipeline.[2]

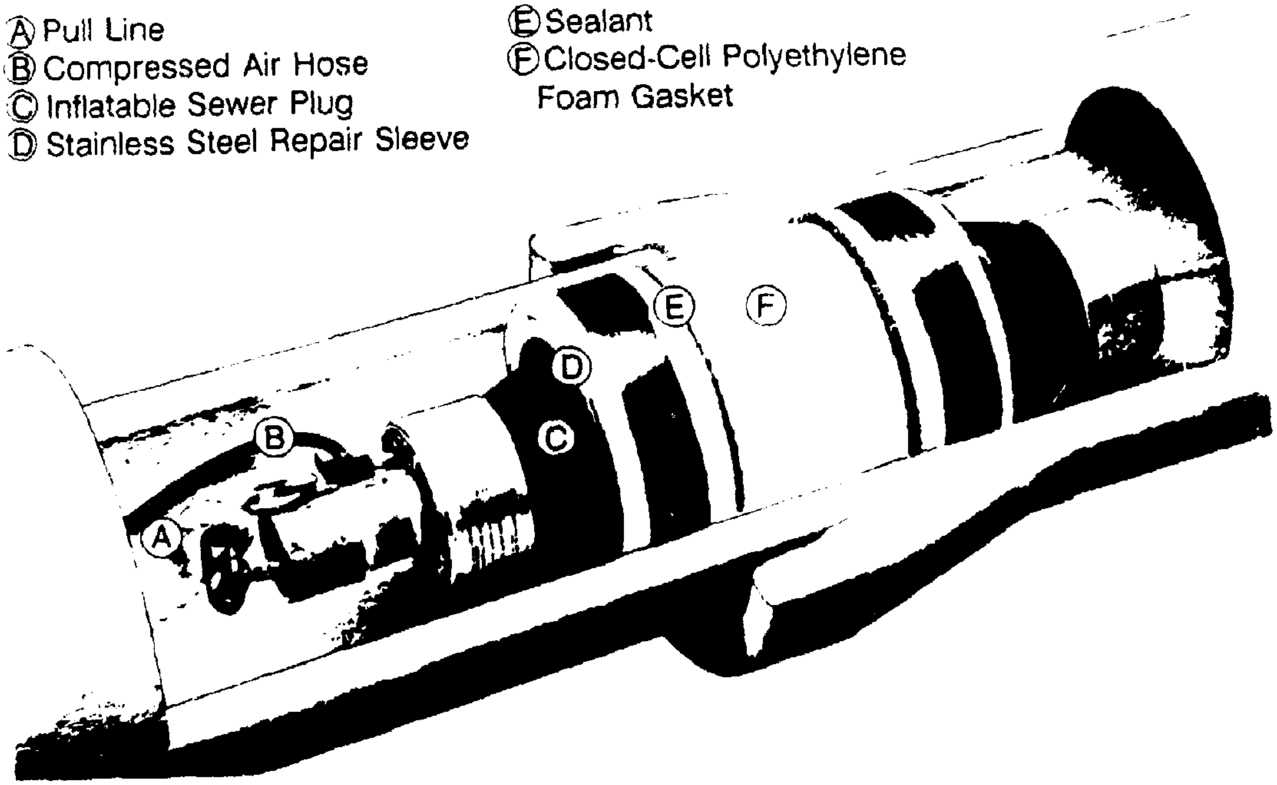


Figure B.34.4. Cut-away drawing of the liner system and installation equipment.[2]

The installation process involves the following steps:

a. Insert the LINK-PIPE^{TM} into the culvert.

b. Insert the pneumatic plug into the LINK-PIPE^{TM} sleeve.

c. Slightly inflate the plug to hold it and the sleeve together while the assembly is being pulled to the location of the damaged pipe.

d. For long culverts, monitor the process with an in-line closed-circuit (video) camera.

e. Inflate the pneumatic plug to expand the liner sleeve and compress the polyethylene gasket.

f. Deflate the pneumatic plug so that the edges of the stainless steel sheet snap together.

g. If necessary, voids behind the liner may be grouted.

4. LINK-PIPE^{TM} PVC Repair Sleeve

This system is designed to repair 24 inch to 108 inch pipelines. The linked sleeve usually consists of six longitudinal segments that are connected together through edges that are grooved to lock each segment in place after installation. The sleeve is wrapped with a closed-cell polyethylene foam gasket that provides a tight seal against the interior of the existing culvert (or pipeline) section. The installation process involves the following steps, which are schematically shown in figures B.34.5 and B.34.6.

a. Place the gasket inside damaged culvert at problem location.

b. Place the folded PVC sleeve inside the gasket.

c. Place a vertical hydraulic jack in the center of the sleeve segment and expand it to lift the crown segment. Compress the gasket between the crown segment and the top of the culvert.

d. Place a horizontal jack between the side flaps and extend the jack until both pairs of side flaps snap into place.

e. Retract and remove the hydraulic jacks. When this is done the gasket expands inward to create a ring compression that holds the segments in place.

f. If necessary, voids behind the liner may be grouted.

Vertical jack expanded,
horizontal jack in place

Link-Pipe PVC

Link-Pipe
expansion completed

Vertical jack in place

Figure B.34.5. LINK-PIPE™ procedures.(2)

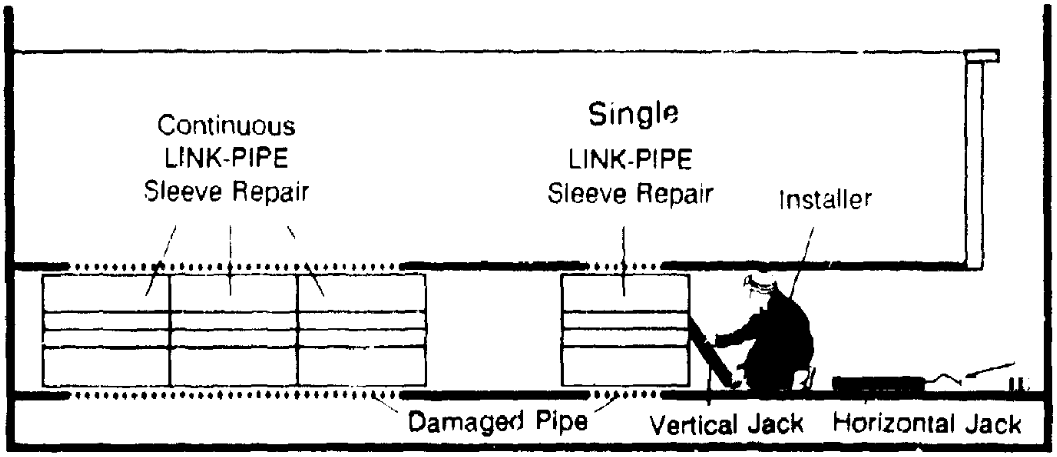


Figure B.34.6. Worker accessible installation of the PVC repair sleeve.(2)

RESOURCE COMMITMENT = 1:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	Heavy		Medium		Low

REFERENCES

1. Jay G. Ramotar, *Culvert Seam Failures and Repairs*, Alberta Ministry of Transportation, Alberta, Canada, 1986.

2. Link-Pipe Technologies Inc., *Remote Stainless Steel Repair Sleeve and Worker-Accessible PVC Repair Sleeve*, Ontario, Canada.

3. *Drainage Technology Bulletin*, National Corrugated Steel Pipe Association, September 1988.

4. *Handbook of Steel Drainage and Highway Construction Products*, American Iron & Steel Institute, Washington, D.C.

APPENDIX B-35: PROCEDURES FOR TIMBER BRACING OF CULVERTS

APPLICATIONS

Timber bracing has application to all types of culverts, but the most common usage is for metal, timber and stone masonry culverts.

COMMENTS

One of the most effective procedures for ensuring that an excessively deformed culvert will not suddenly collapse is to install temporary struts or braces in the culvert.

The main disadvantage of installing braces inside a culvert is that they will tend to constrict or disrupt the smooth flow of water through the culvert. Of particular concern should be the fact that the braces may snag debris that is carried by the water and create a wall that may totally block the culvert. The hydraulic forces that are created by such a blockage may subsequently break or dislodge the bracing and cause a catastrophic collapse of the culvert, perhaps during the height of a storm. The blockage of the culvert can also cause flood waters to overtop the roadway.

Thus, braces should be installed only when they are essential to prevent collapse. If they are used, they should be designed to minimize the space they take up, but at the same time be sufficiently strong to resist all but the strongest hydraulic forces.

It should be noted that the use of timber bracing is a temporary solution that is intended to prevent further deterioration and/or collapse of a culvert. The culvert should be inspected regularly while the bracing is in place. A permanent repair should be designed and undertaken as soon as possible.

PROCEDURES:

The basic procedure is to install vertical braces between the crown and the invert throughout the entire section of the culvert that has excessive deflection. Timber sills should be placed below and above the braces, so that the support loads will be spread out along the length of the sills and not be point loads at the ends of the braces. The butt joints of the top and bottom sills should be staggered, so that they do not occur at the same location in the culvert.

The braces should be structurally designed to carry, with an adequate margin of safety, the weight of the volume of soil that is statically proportioned to them by assuming the propped cross-section to act as a two-span continuous beam.

The spacing of the braces will depend upon the soil forces to be resisted and upon the type of brace used. Braces are normally installed at 3- to 5-foot spacing. The sills above and below the braces should be long enough to hold at least two braces.

A variety of types of braces may be used. The most common may be 8 inch x 8 inch timbers. Another common type of brace is the hollow tubular steel brace that is frequently used in construction formwork. The advantage of the latter type of brace is that the end of the tubular section has a threaded coupling that permits easy adjustment of the length and the application of at least some force, to take up any slack space in the bracing system.

If the sides of the culvert are al[illegible]ssively distorted, it may be necessary to install horizontal braces, which s[illegible] be attached to the vertical braces.

RESOURCE COMMITMENT = 2: 5 4 3 2 1
Heavy Medium Low

COST RELATIVE TO REPLACEMENT = 2: 5 4 3 2 1
High Medium Low

REFERENCES

APPENDIX B-36. PROCEDURES FOR REROUNDING/RESHAPING CORRUGATED METAL CULVERTS

APPLICATIONS

The following methodology may be used for rerounding or reshaping distorted corrugated metal pipe and pipe arch culverts.

COMMENTS

Although it may be technically possible to adjust or reround deformed corrugated metal pipe and pipe arch, it may not be practical. The overall condition of the culvert should be assessed, as well as the soil-structure conditions that either caused or allowed the deformation to occur. The type and size of the culvert as well as the type, location, and degree of deformation will also have a direct bearing on whether it is practical to try to reround the culvert. For example, symmetrical deflection of the crown may be indicative of problems with support of the bottom of the culvert or insufficient backfill over the top of the culvert. Unsymmetrical deformation of the top of the culvert may be the result of loss of soil support on one side of the bottom or improper compaction of the backfill on one side of the culvert. Thus, the conditions that caused the deformation must be assessed and the rehabilitation plan must include not only rerounding the culvert but also correcting the underlying problem.

There are basically two approaches for reshaping deformed corrugated metal culverts. One is through a combination of work from the outside and from the inside of the culvert, and the other is to work entirely from the inside of the culvert.

PROCEDURES:

1. Work from the Outside and the Inside of the Culvert

The basic concept for this approach is to remove the backfill from above the culvert, reshape the culvert from the inside, and replace the backfill, as described in appendix B-37 in the procedure for repairing and strengthening the crown of culverts. This approach would be used when it was determined that depth of the backfill above the culvert was sufficiently shallow that the most economical procedure would be to remove the overburden rather than to work entirely from the inside of the culvert.

The primary difference for this procedure is that the deformed sections of the culvert would not be removed, but rather moved into their proper position through the use of portable hydraulic jacks after the outer backfill material has been removed. The following are some points that should be considered in planning this operation.

a. Working around jacking systems has a certain amount of risk, and precautions should be taken to minimize the risk to personnel during the operation. Particular attention should be given to placement and orientation of the jacks so that they, and/or timbers that they are reacting against, will not buckle out of position when force is applied.

b. Spreader beams should be installed under the hydraulic jacks and at point where the load is being applied to distribute the load so that a more-or-less uniform load is applied without causing local bending of the culvert at the point of load. It may be appropriate to place a section of similar corrugated metal between the existing culvert and the applied load to reinforce the corrugations.

c. It may be necessary to over-bend (over-correct) the distortion, so that when the jacking load is removed the culvert will rebound into the proper position. It should not be expected that proper compaction of the backfill (by itself) will resist the elastic rebound of the culvert as it will attempt to return to its distorted shape.

d. Depending upon the location of the distortion and the cause of it, it may be appropriate to install a cast-in-place concrete slab above the reshaped culvert, as described in appendix B-37: Procedure for Repairing and Strengthening the Crown of Culverts.

2. Work from the Inside of the Culvert

When the depth of the culvert is too deep to economically remove the backfill from above it, it may be possible to reshape a corrugated metal culvert by working entirely from the inside of the culvert. Although this may seem to be an extreme situation, such conditions may occur: for example, for a long culvert under an interstate highway intersection, where (1) only a small portion of the culvert is affected; and (2) the size of the culvert is only marginally adequate and a reduction in the flow capacity would further reduce the hydraulic capacity of the culvert. The objective of this rehabilitation effort is to restore the cross-sectional area and flow characteristics. As noted above, consideration must also be given to correcting the problem that caused the deformation. The procedure will include the following steps:

a. Remove the indented or distorted section of the culvert with a cutting torch. Care must be given to protect the workmen from the fumes created by cutting a galvanized coating. It may be necessary to temporarily strengthen the culvert sections adjacent to the section to be removed by installing tunnel lining segments, as described in the appendix B-34: Procedures for Repair at Distorted Sections. The difference here is that when the repair work is completed, the internal shape and area of the culvert will be restored.

b. Remove the backfill material that was behind the distorted section. Consideration should be given to the need to remove a considerable amount of material, so that when the void is subsequently grouted, the volume and shape of the grout will not only fill the void but will also provide additional strength and distribution of future soil loads to and around the culvert without creating future distortion.

c. Replace the removed and reshaped section, or a new section of similar culvert material, by welding.

d. If necessary, install an internal expanding band of similar culvert material to strengthen the joint between the existing and the reshaped culvert sections, as mentioned in the appendix B-26: Procedure for Sealing Culvert Joints.

e. Pressure grout the voids behind the formerly distorted section as well as behind sections that created voids as they were removed to restore the symmetrical shape of the culvert. Information on grouting is provided in appendix B-30: Procedures for Grouting Voids Behind and Under Culverts.

Note: Special attention should be given to the location of grout ports and ventilation ports that will permit proper installation of the grout and venting of air as the grout is installed.

RESOURCE COMMITMENT = 4:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 3:	5	4	3	2	1
	High		Medium	Low	

REFERENCES

APPENDIX B-37. PROCEDURES FOR REPAIRING AND STRENGTHENING THE CROWN OF CULVERTS

APPLICATIONS

The following procedures have application to all types of culverts that have problems that are primarily located at the crown.

COMMENTS

Many types of culverts may sustain damage in their crown section that is due primarily to the depth of cover being too shallow to adequately support and distribute vehicle live loads. The result may be cracking, spalling, and distortion of concrete culverts, and distortion and tearing at bolt holes of metal culverts.

If the depth of cover is shallow and the amount of distress of the culvert is not excessive, it may be possible to repair and strengthen the existing culvert. The cost effectiveness of the following procedure will depend upon the size, type and location of the culvert. The procedure involves removal of the soil cover, repair of the damage to the culvert, and installation of a concrete slab around and above the upper portion of the culvert. The addition of a composite-reinforced concrete slab not only repairs the damaged culvert crown, but it may also overcome the problem of too shallow a depth of cover.

PROCEDURES:

1. Remove the backfill material from above and around the upper portion of the culvert.

2. Repair the damaged portion of the existing culvert. This may include:

    a. Removal and replacement of the damaged upper portions of metal culverts with similar material that is securely fastened into position. It may be necessary to cut out bent and/or distorted sections of circular or oval CMP. Care should be taken to properly position the replacement sections of metal plate so that tearing at bolt holes will not occur at a later date.

       As indicated in appendix B-38: Procedure for Repairing Corrugated Metal Structural Plate Seams, the replacement section should be assembled so that the bolts nearest the visible edge are on the crests of the corrugations rather than in the valleys.

    b. Removal of damaged sections of concrete pipe and replacement of the damaged section with cast-in-place concrete. If possible, the existing cage of steel reinforcing should not be cut.

3. Install shear studs (for metal culverts) or bolts (for concrete culverts) to ensure composite action between the culvert and the subsequently placed concrete.

4. Install reinforcing steel above the culvert to reinforce the cast-in-place concrete.

5. Install and finish cast-in-place concrete around the upper portion and above the culvert.

6. Replace the backfill above the culvert with proper compaction.

RESOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 2:	5	4	3	2	1
	High		Medium		Low

REFERENCES

APPENDIX B-38. PROCEDURES FOR REPAIRING CORRUGATED METAL STRUCTURAL PLATE SEAMS

APPLICATIONS

The following procedures may be used for repairing cracked longitudinal seams in corrugated metal structural plate culverts.

COMMENTS

Tearing or cracking at bolt holes occurs primarily along the lower longitudinal bolt line and normally on only one side of the structure. The most prevalent cause of such cracking is incorrect assembly of the lap joint. It has been found that the joint should be assembled so that the bolts nearest the visible edge of the joint should be in the valley. This rule is valid regardless of whether the joint is viewed from the inside or the outside of the culvert. Such cracking also may be due to misalignment of the plates at the last splice to be made in a given section. Another possible cause is excessive deflection due to unstable bedding and poor backfill. The excessive deflection causes a bending moment at the splice lap. In addition, over-torquing the bolts when attempting to pull the plates together for a tight fit may cause tearing or cracking at the bolt holes.

The following are two methods that have been used to repair culverts that have cracked longitudinal seams. Repair of such cracks will not stabilize an unstable culvert, but such repairs may prevent the development of an unstable condition.

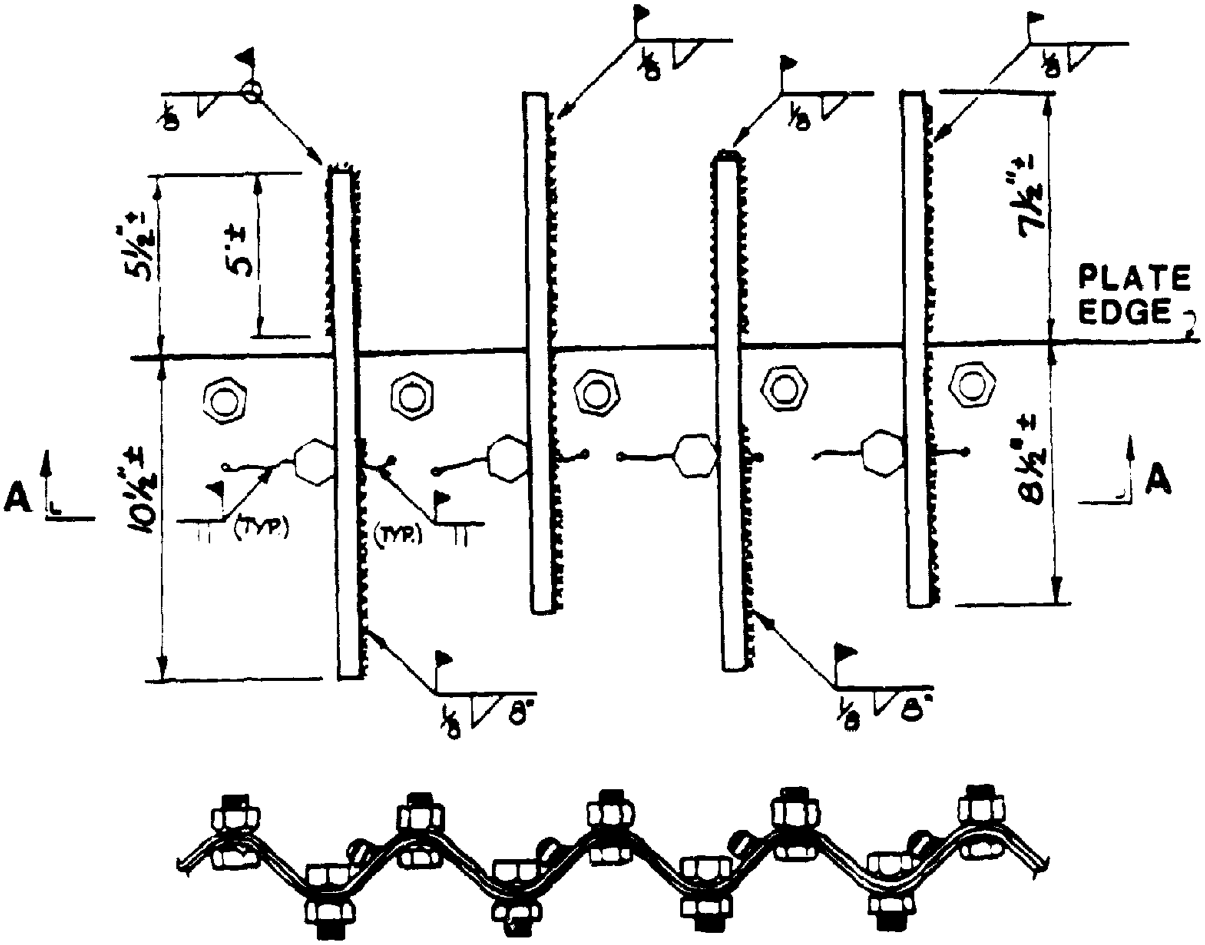
PROCEDURES

1. Repairs with Reinforcing Bars

   The following procedure is routinely used by several state highway agencies to repair cracks in seams, through bolt holes. The procedure involves welding # 5 reinforcing bars across the seam, as shown in figure B.38.1. The method is economical and relatively easy to use.

   a. Establish the length at the splice where cracking or tearing is occurring. Use of dye penetrant may be required at the extremities to make sure that the total length of repairs to be made is established. If there is any doubt, the total section (10 or 12 feet) should be repaired.

   b. 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.



SECTION A-A

(**Note**: The plates shown are assembled so that the bolts nearest the visable edge are on the crests of the corrugations rather than in the valleys. This placement is the opposite of current recommendations and may have led to the tearing of the bolt holes requiring repair.)

1. Drill 3/16-inch diameter holes at each end of each crack.
2. Weld each crack.
3. Weld #5 bars across each crack and lap as shown.
   a. All bar lengths are the same, 16-inch+.
   b. Place adjacent bars staggered as shown.

Figure B.38.1. Procedure for correcting bolt hole cracking.

c. Place the plain #5 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.

d. Tack weld the bar to both plates. Complete the weld on the side of the bar near the peak. Welds should be approximately 1 inch long and spaced approximately 2 inches apart, depending on obtaining good contact between plate and bar. Excessive amounts of welding must be avoided on these relatively thin plates (0.105 inch to 0.276 inch) to avoid distortion and/or puncture due to heat.

SAFETY PRECAUTIONS

Fumes from galvanizing caused by the heat of welding can be toxic in confined areas. The galvanizing should be removed as much as is practical and the welder should wear a mask.

SPECIFICATIONS

No specifications apply directly to this type of work. Standard specifications should be used for the reinforcing bar. Standard welding procedures including size and type of rod should be followed.

2. Repair with a Shotcrete Beam

The Alberta (Canada) Ministry of Transportation has developed and used the following procedure to repair approximately 236 m of cracked longitudinal seams on four SPCSP culverts, in the winter of 1985. "Some of the repairs were done on seams located in the top arc. The culvert diameters ranged from 2.4 to 4 m in diameter, and had significant ice buildup along the invert at the time the work was done One culvert has a series of fish weir-type baffles along the invert. Application of any other repair method would have required removal of the ice and the baffles. They would have also significantly reduced the hydraulic capacity of the culverts."(3)

The shotcrete that was used above the floor consisted of a 9,400 psi compressive strength steel fiber reinforced mix without reinforcing bars. A silica fume admixture was used in the mix to reduce rebound losses. (Additional information on shotcrete is provided in appendix B-11.)

One of the critical phases of this repair method is to ensure proper connection between the steel brackets and the SPCSP plates. As shown in figures B.38.2 and B.38.3, these brackets consisted of U-shaped galvanized steel, 2.7 mm thick. They were attached to the SPCSP plates using Hilti pins. The plate thickness ranges from 3 mm to 5 mm. The variation in plate thickness required careful selection of the Hilti pins, driving guns, and cartridges. Their recommendations, based on experience, are:

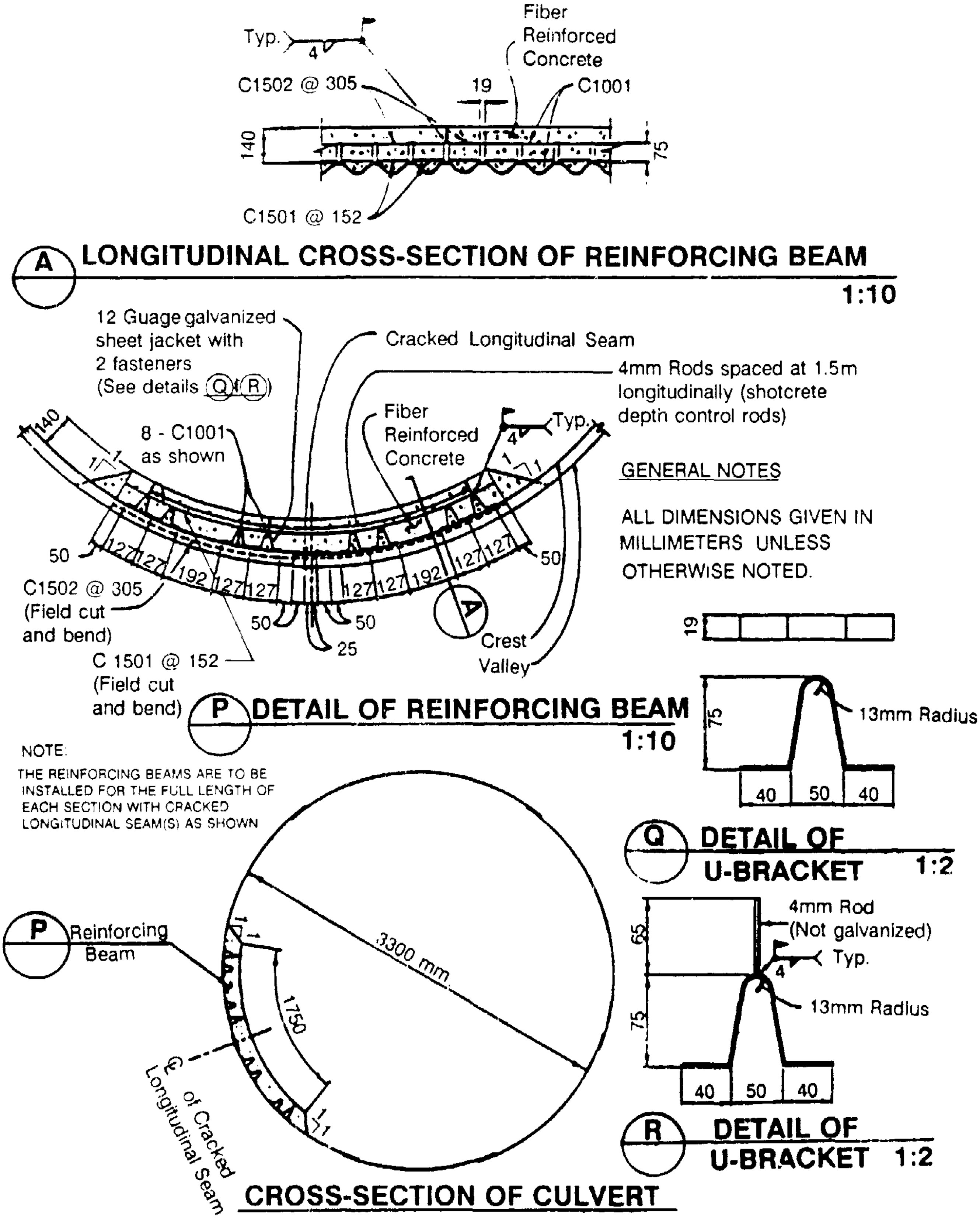
PLATE THICKNESS	HILTI GUN	PINS	CARTRIDGES
4 mm	DX 450	ENK 19S12	Red
4.3 mm	DX 650	ENP 3-21-L15	Yellow
5.0 mm	DX 650	ENP 3-21-L15	Red

As shown in figure B.38.2, the brackets were arranged in two different ways: one had the brackets pinned along the centerline of the inside crest, and the other had the brackets pinned to the tangent portion of the corrugations.

The first arrangement provides higher rigidity against the driving energy of the gun, which helps avoid loose connections on thinner plates. The second arrangement has the advantage of placing the Hilti pins in a shear mode rather than a "pulling-out" mode, which results in stronger connections on all plate thicknesses providing the driving energy of the gun is properly adjusted.

Prior to shotcreting, the culvert sections with cracked seams were hoarded in 15 m lengths and heated using 2 or 3 propane heaters. The SPCSP plates were lightly sandblasted to provide a textured rough surface without removing the zinc coating. The plates were then washed with an air-jet immediately before shotcreting. This was done in lengths not exceeding 5 m so as to minimize oxidation of the reinforcing steel.

The specified minimum hoarding temperature during the shotcreting operation and the following 72 hours was 20°C. Since the work was done in winter conditions, the SPCSP plates heated up slower than the rebars and anchors. Also, the temperature of the plates varied, with the temperatures decreasing near the ice at the invert. The minimum specified bond surface temperature was 5°C. In order to maintain the minimum temperature of the shotcrete mix at 15°C during shooting, the mixing water and the pre-bagged mix were also hoarded and heated with a propane heater.

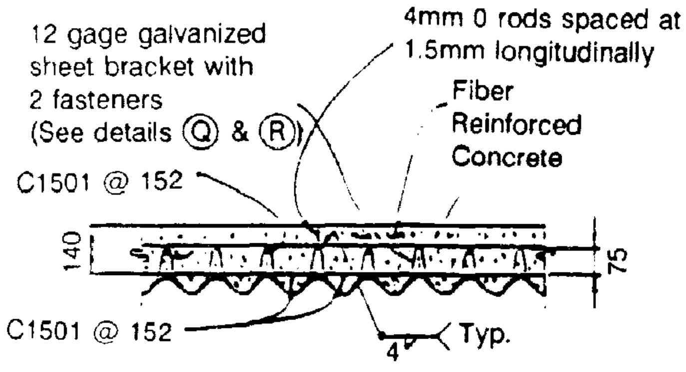


GENERAL NOTES

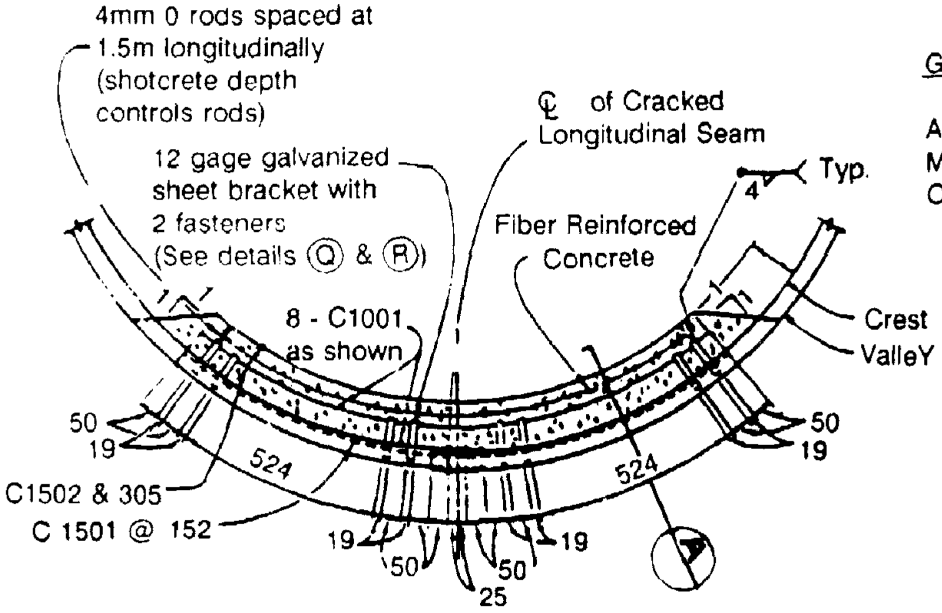
ALL DIMENSIONS GIVEN IN MILLIMETERS UNLESS OTHERWISE NOTED.

NOTE:
THE REINFORCING BEAMS ARE TO BE INSTALLED FOR THE FULL LENGTH OF EACH SECTION WITH CRACKED LONGITUDINAL SEAM(S) AS SHOWN

Figure B.38.2. Repair of a 3.3 m culvert with shotcrete beam.(3)



Ⓐ LONGITUDINAL CROSS-SECTION OF REINFORCING BEAM
1:10

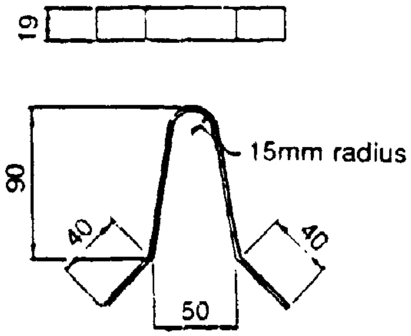


Ⓟ DETAIL OF REINFORCING BEAM
1:10

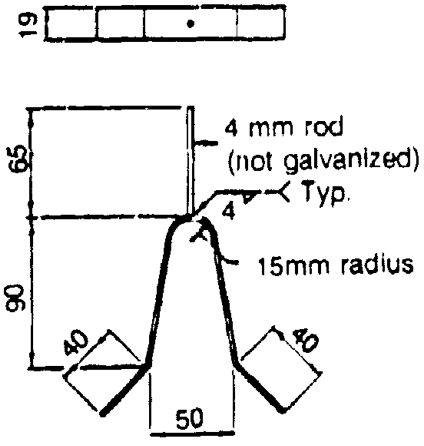
NOTE: THE REINFORCING BEAMS ARE TO BE INSTALLED FOR THE FULL LENGTH OF EACH SECTION WITH CRACKED LONGITUDINAL SEAM(S) AS SHOWN.

GENERAL NOTES

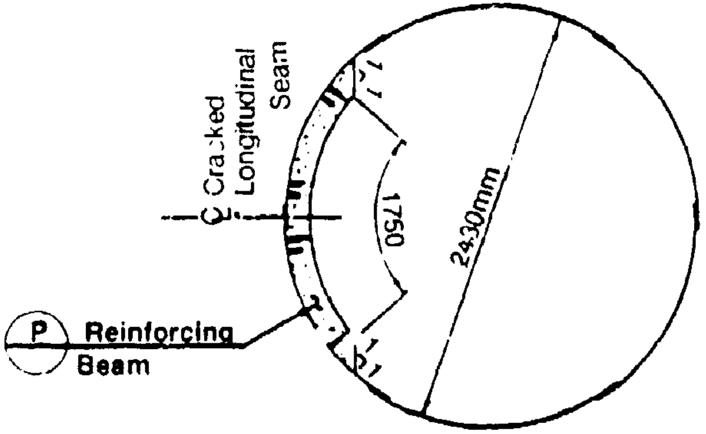
ALL DIMENSIONS GIVEN IN MILLIMETERS UNLESS OTHERWISE NOTED.



DETAIL OF
Ⓠ U-BRACKET
1:2



Ⓡ DETAIL OF
U-BRACKET
1:2



CROSS-SECTION OF CULVERT 1:20

Figure B.38.3. Repair of a 2.4 m culvert with shotcrete beam.[3]

A slurry coat was applied to the area receiving the shotcrete. Two rough coats of shotcrete were then applied, allowing 1 hour set time for each coat, to a maximum thickness of 100 mm to avoid debonding. After about 1-1/2 hours of set time the finish coat was applied to establish the designed thickness and curvature. Thickness control was monitored by using three rows of depth gauges located at the top, middle and bottom of the beam and at 1.5 m intervals along the longitudinal axis of the culvert. The thickness was checked using a 4 m long straight edge.

RESOURCE COMMITMENT = 2:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 2:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. David C. Cowherd and Vlad G. Perba, "An Evaluation of Flexible Metal Pipes." Bowser-Morner Associates, Inc., Dayton, Ohio.

2. "Handbook of Steel Drainage and Highway Construction Products." American Iron & Steel Institute, Washington, D.C., 1983

3. Jay G. Ramotar, "Culvert Seam Failures and Repairs," Alberta Ministry of Transportation, 1986

4. "Hilti Fastening Systems," Hilti Fastening Systems, Inc., Tulsa, Oklahoma.

APPENDIX B-39: PROCEDURES FOR SLIPLINING CULVERTS

APPLICATIONS

The technique of sliplining may be used to line almost all types of culverts with many of the types and shapes of metal, concrete or plastic products that are commonly used to construct culverts. In addition existing culverts may also be lined with non-structural types of plastic pipe products.

COMMENTS

As noted in Chapter 6, one of the more effective ways to restore a culvert to a functional condition is by sliplining the existing culvert with either conventional or new types of prefabricated culvert products. In a sense, almost any type of culvert can be sliplined with almost any kind of culvert material.

There are many technical details that must be worked out for the actual construction project, including: (1) how the liner sections will be moved into place in front of the culvert, (2) how the sections will be slid into the culvert, and (3) if and how structural interaction will be established between the liner and the existing culvert. Although there are some procedures that are relatively simple and straightforward, others are much more complex. In some cases it may be possible to stipulate standard construction procedures while at other times the procedures should be left open for contractor innovation, which may permit a contractor to use special equipment or techniques that may reduce the cost of the work.

With regard to innovative engineering and construction practices, it may be worthwhile to note that plastic pipe is somewhat flexible and it can be deformed to fit unusual culvert conditions and shapes. It has been reported that on one project in the State of Indiana, a section of 32 inch diameter Snap-Tite™ was deformed to fit into a 24 inch high pipe arch culvert. The process involved placing one 4 inch x 4 inch timber along the center of the invert and another directly above it, under the centerline of the crown. Several portable hydraulic jacks were then used to push the two timbers apart, creating an oval cross-section to the plastic pipe. The oval-shaped plastic pipe was then rolled 90° and then pushed into the pipe arch culvert. Multiple sections of the plastic liner pipe were similarly changed in shape and subsequently snapped together to form the continuous liner. The space between the culvert and the liner was later grouted, in accordance with procedures described appendix B-40.

The following describes the steps that are involved in sliplining process and some of the individual techniques that have been used for specific projects. Information on three sliplining projects is provided at the end of this section.

PROCEDURES:

There are a wide variety of individual techniques that may be used to slipline a culvert. The choice of technique depends upon site-specific conditions and the selected sliplining material as well as the contractor's knowledge and experience with this type of work. The equipment that must, or can, be used for the work is also a consideration. The following steps are normally required for the sliplining process:

Control water passing through the culvert - Water that is flowing, or could flow, through the culvert must be controlled or diverted so that the existing culvert may be repaired and/or relined. It is customary to construct a check-dam across the channel above the culvert and then install a pipe or pump system for moving the water through or around the culvert. This may also include diversion of sideslope channels and secondary check-dams to prevent surface runoff of water through the culvert during rainstorm periods. Examples of such control features are shown in figures B.39.8 and B.39.10.

Prepare culvert for sliplining - The culvert must be prepared for the sliplining operation. This will usually include dewatering and doing at least a minimum amount of necessary repair work. The type and amount of preparation work will depend upon the condition of the existing culvert, the type of slipliner to be installed and whether the space between the liner and the existing culvert will be grouted to provide structural interaction between the liner and the existing culvert.

Construct guideway for sliplining - Consideration must be given to how the liner segments will be moved inside the culvert and whether they should be slid on some sort of guideway system. It has been found that the variety of ways that these operations are done is a function of site conditions; the condition of the existing culvert; the type, size, and weight of the liner sections; the clearance space between the existing culvert and the liner; the contractor's experience and innovativeness; and the equipment available for the task.

Frequently pairs of wooden timbers are used to construct a "railway" that the sections may be slid on. This procedure may not be feasible if the invert of the existing culvert is badly deteriorated and uneven. Another system that is also frequently used is to form up and cast a concrete slab down the centerline of the existing invert. This has the dual function of repairing the invert and providing a smooth surface on which the liner sections may be slid. The surface of the "sidewalk" may be either flat or shaped to conform to the shape of the liner. In addition, the elevation of the "sidewalk" can be set to provide excellent grade control for the liner and the final elevation of the relined culvert. For arch and some other types of culverts it may be possible and desirable to excavate and lower the elevation of the invert or streambed so that the elevation of the invert of the liner will be the same as the original grade. Another method that has been used for large precast concrete liner segments is to construct a railway with surplus steel light-rail track. The liner sections are then lifted, rolled, and set into place with a special bogie vehicle that has flanged steel wheels.

It is also possible to establish gradelines inside the existing culvert with survey-set laser equipment that can be set to any desired slope. The laser beam is usually set at a convenient elevation above the invert. A survey rod, or equivalent, may then be used to check the grade of the liner sections by the offset method.

Slipline liner segments into the culvert - The overall concept of this technique is to line the existing culvert with another (smaller) culvert product, by sliding the new sections into the existing culvert. This operation is commonly termed "launching." The complexity and difficulty of the launching operation is a function of the type and size of the existing culvert and the product that is used for the new lining. For example, lining a small concrete pipe culvert with a somewhat smaller concrete or plastic sections is relatively simple and straightforward, whereas lining a large corrugated metal culvert that has a distorted and corroded out invert with a somewhat smaller corrugated metal culvert may require considerable planning and preparation work.

It should also be recognized that prefabricated metal and reinforced concrete culvert sections are designed to be lifted and set into place on a specially prepared base of compacted soil or base course material. They are then incorporated into the roadway by compacting soil around them in a prescribed manner. This procedure is not only not followed for sliplining, it is substantially deviated from by the requirements imposed by the sliplining process. Specifically, sections are lifted and set down in front of the existing culvert and they are then slid into and along the inside of the culvert until they reach their final position.

Although there are several techniques that may be used to install a slipliner, they all involve either pushing or pulling the individual segments together and through the culvert. Frequently the sections are pulled into the culvert with a cable that is attached to a crane or a piece of construction equipment. Depending on site conditions the cable may be pulled from the "far" end of the culvert or it may be run from the segment to the "far" end of the culvert, through a pulley block on a strongback frame and then back through the culvert and the liner to the "near" end of the culvert.

It should be noted that at some appropriate point in the process the liner segments must be connected together. When this operation is undertaken will depend upon the type of liner to be used; for example:

- Precast concrete segments are connected together inside the culvert.
- Corrugated metal segments are normally connected together outside of the culvert.
- Plastic liner segments may be snapped together inside or outside of the culvert or they may be fuse/welded together outside of the culvert.

Grout or seal liner - Although the process of sliplining provides a new interior surface in the culvert, the liner will usually not be stable and resistant to hydraulic and structural loads until the annular space between the existing culvert and the liner is filled with some type of grout material. Grouting completes this type of construction and re-establishes structural support and interaction between the surrounding soil (including the existing culvert) and the new liner. In addition, grouting also helps retard corrosion of the existing culvert and it blocks further infiltration through the wall of the existing culvert, if that has been occurring. Such infiltration may create voids in the soil adjacent to the culvert barrel, causing an undesirable distribution of soil pressures around the existing culvert. The worst-case scenario might be the eventual collapse of the existing culvert into the ungrouted space, which may then lead to collapse of the liner and many associated problems at the level of the roadway surface.

The procedures and materials that are to be used for grouting the annular space between the outside of the liner and the inside of the existing culvert should be carefully considered with regard to the purpose and requirements for the grout. If the existing culvert is structurally weak and the liner is to carry significant structural loads, then the filling (grout) must completely fill the space, without large voids or air pockets in the grout. If the existing culvert is structurally strong and the liner will only carry water and resist outward radial forces from the water, then it may be allowable for the grout to be a weaker material and to have some voids. Incomplete filling resulting in voids will create uneven distribution of forces, which could cause future distress and damage to the culvert liner.

It is very important to recognize that the liner must be adequately blocked, or the grouting procedures must be selected to avoid displacement and damage to the liner during the grouting operation, due to flotation. A considerable buoyant force may be exerted on the lining by the fluid cement-based grout; which tends to float the liner to the top of the existing culvert. This can raise the level of the invert of the liner and possible cause structural damage to the liner. Although the buoyant force is resisted by the weight of the liner units, there is still a considerable buoyant force that is proportionately larger with larger size culverts. For example, the buoyant force on a circular liner, in 150 pcf concrete, is approximately 1,900 pounds per lineal foot on a 4 ft diameter liner and 8,600 pounds per lineal foot on an 8 ft diameter liner. The use of non-uniform or inadequate blocking may also cause point loading, bending and cracking of the liner. Since having a cold joint is not of concern, the grout may be placed in several small lifts to avoid flotation problems More detailed information on grouts and procedures for grouting sliplined culverts is provided in Chapter 6 and in appendix B-35.

It must be recognized that some sort of end dam must be constructed at the ends of the culvert to contain and resist fluid forces that will be exerted by the grouting operation. This dam may be of a temporary type of construction or it may be construction of new headwalls at the ends of the culvert.

It should also be noted that the Tennessee highway department, and possibly other agencies, do not completely grout the annular space between the liner and the existing culvert, especially when sliplining with a non-rigid plastic liner. Their practice is simply to seal this annular space at the upstream end of the culvert with a non-shrinking, semi-flexible type of grout or a resin-impregnated type of rope product that expands and completely fills the space.

Sliplining of a 10-cell Reinforced Concrete Box Culvert in Abilene, Texas

Objective: Widen roadway and increase load capacity of the existing culvert.

Procedure: Clean out existing inverts. Cast trough-shaped concrete base to establish grade and to facilitate sliding installation of 8 ft diameter corrugated metal culvert pipe liner in 10 ft square cell openings. Cast new concrete headwalls. Fill annular space between existing culvert and liner with Texas-style "flowable fill" (see appendix B-35).

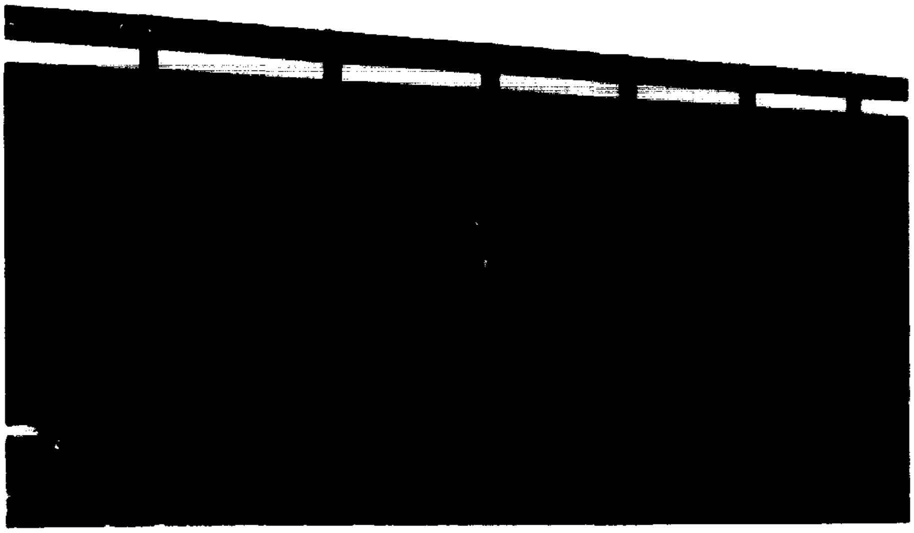


Figure B.39.1. View of existing ten-cell reinforced concrete box culvert.

Figure B.39.2. View of box webs on footings and shaped concrete slab for installation of circular corrugated metal culvert pipe liner.

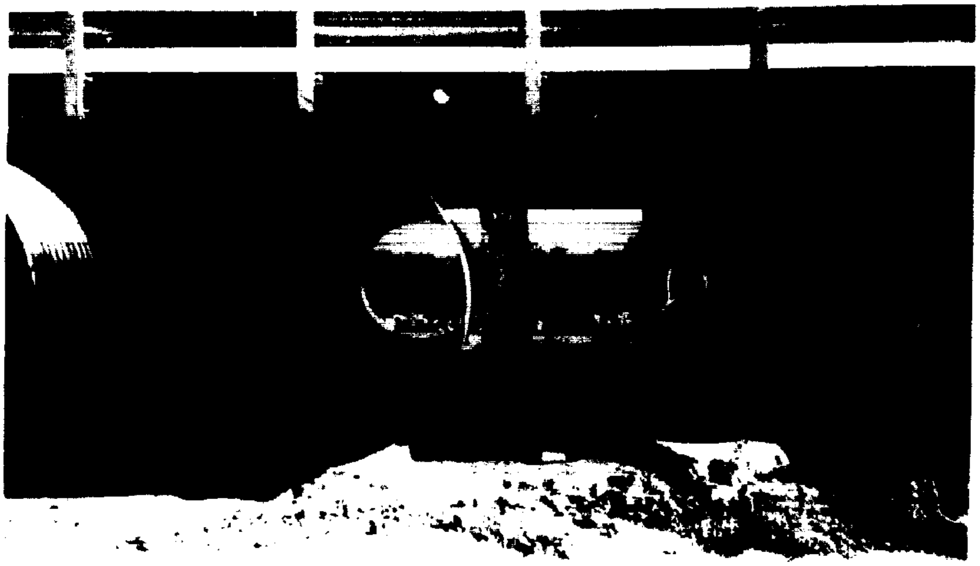


Figure B.39.3. View of corrugated metal pipe liner in cells of existing box culvert.

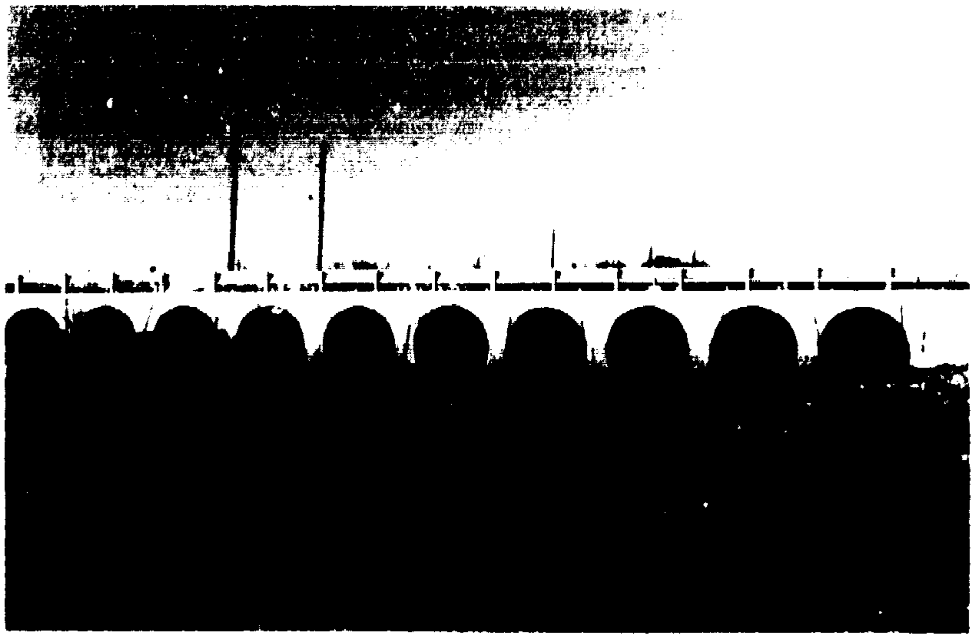


Figure B.39.4. View of completed project with new concrete headwall.

Sliplining of a Reinforced Concrete Arch Culvert in Larksville, Pennsylvania

Objective: Strengthen existing culvert and improve hydraulic efficiency.

Procedure: Install sandbag check-dam upstream of culvert and plastic pipes to carry drainage water through culvert. Clean out existing invert. Install light-rail steel track, laser grade-control equipment, and steel strongback with pulley so that the oval precast concrete culvert liner sections can be pulled into the culvert with a crane, which also lowered the liner sections onto a wheeled bogie carrier. Cast new concrete cutoff wall and head- and wingwalls. Grout annular space between culvert and the installed liner.

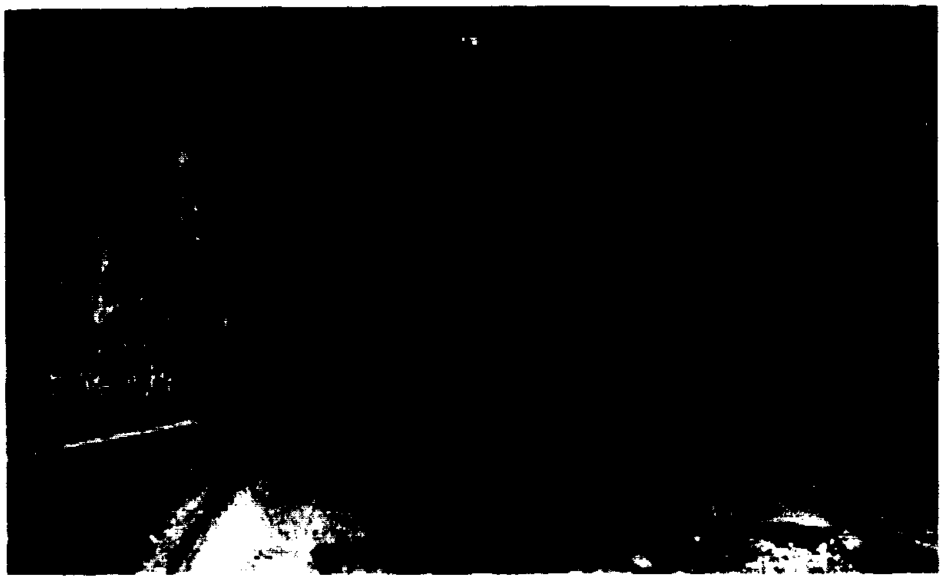


Figure B.39.5. Existing concrete arch culvert with installed light-rail track.

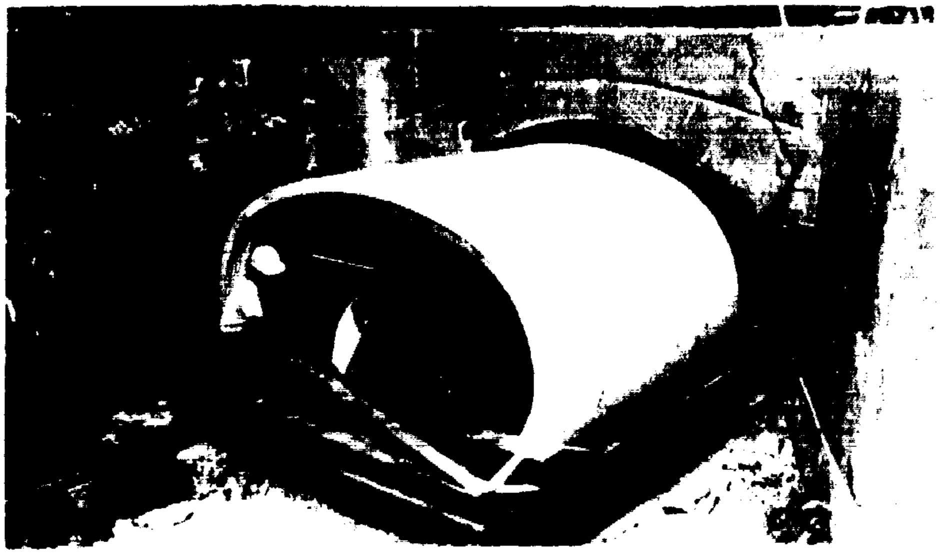


Figure B.39.6. Rolling precast concrete pipe sections into culvert on bogie.

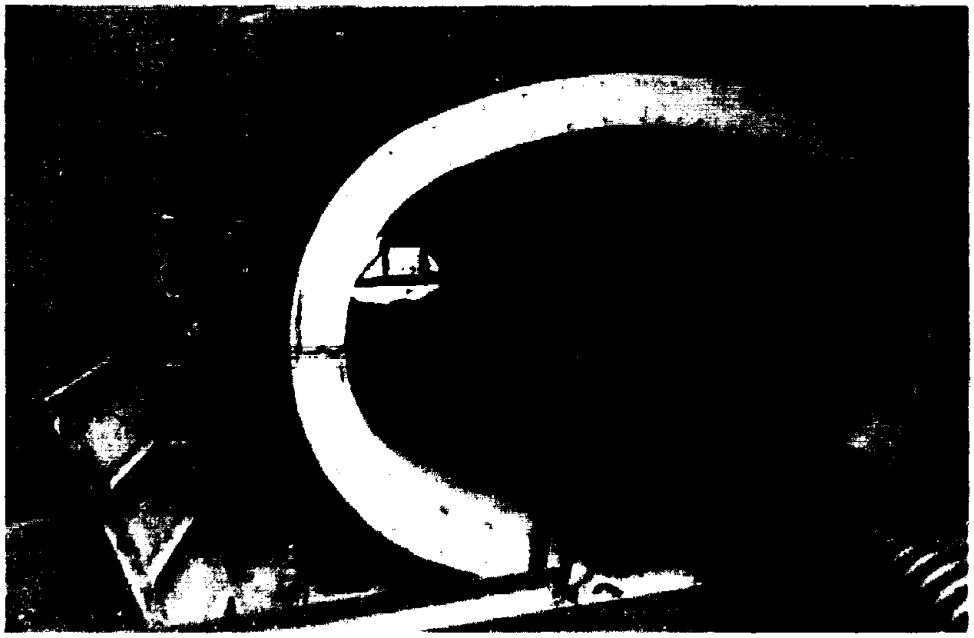


Figure B.39.7. View shows installed precast concrete section, laser equipment, and protruding grouted steel reinforcing bars for attachment of new reinforced concrete head- and wingwalls.

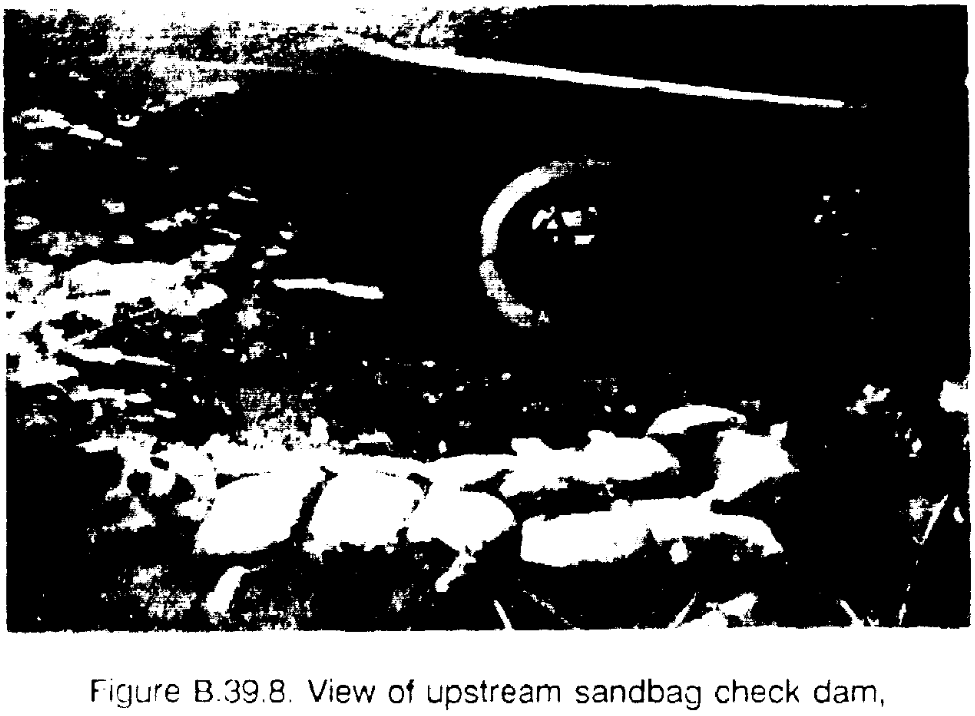


Figure B.39.8. View of upstream sandbag check dam, plastic pipe to run drainage water through culvert, and steel beam strongback for pulling liner sections into culvert.

Sliplining of Twin Barrel Corrugated Metal Culvert in Woodbridge, Virginia

Objective: Repair corroded invert and strengthen existing culvert.

Procedure: Divert water through adjacent barrel. Dewater void under existing invert. Cast concrete slab to fill erosion hole under invert, to establish grade and to facilitate sliding installation of 66 in diameter precast concrete pipe liner sections into 96 in vertical oval corrugated metal barrel. Repeat process on other barrel. Enclose ends of annular space between culvert and liner and grout space with controlled low strength grout.

Figure B.39.9. Installation of concrete slab that overfills void under invert, establishes grade, and facilitates installation of liner sections.

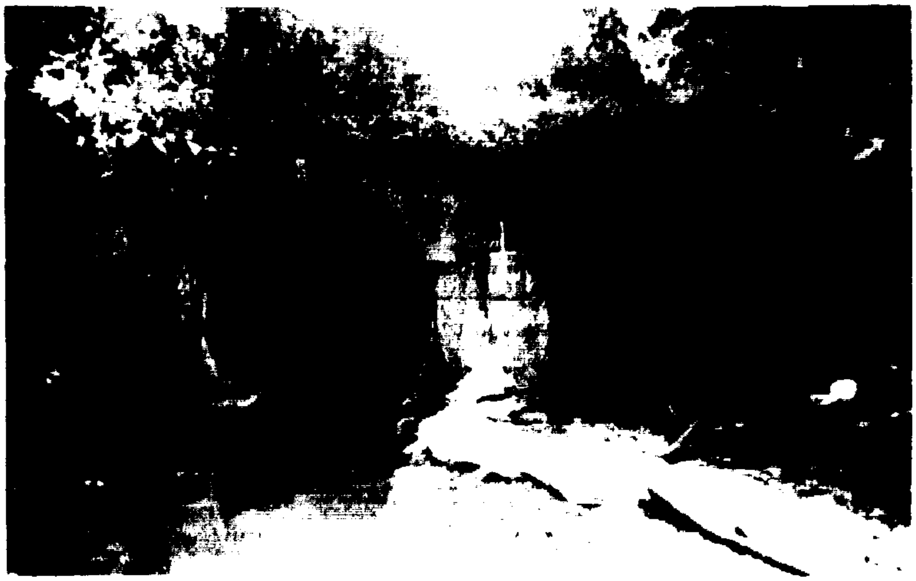


Figure B.39.10. Upstream end of culvert, showing dewatering and installed liner.

Figure B.39.11. View of downstream end of culvert, that shows steel I-beam strongback used with a pulley and cable to pull liner sections into culvert.

Figure B.39.12. View of bricked up space between liner and culvert, with protruding pipe for grouting annular space.

RESOURCE COMMITMENT = 4:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 3:	5	4	3	2	1
	High		Medium		Low

REFERENCES

APPENDIX B-40. PROCEDURES FOR GROUTING SLIPLINED CULVERTS

APPLICATIONS

The following deals with the materials and procedures that may be used to grout sliplined culverts, including (1) concrete inside of concrete, (2) corrugated steel inside of concrete, (3) concrete inside of corrugated steel, (4) corrugated steel inside of corrugated steel and (5) corrugated steel or concrete inside of either masonry or timber.

COMMENTS

The procedures and materials that are to be used for grouting the annular space between the outside of rigid sliplined culvert liners and the inside of existing culverts should be carefully considered with regard to the purpose for filling and the strength of the grout material that should be used. The grout may not need to have the strength of structural concrete but rather only the strength of well compacted soil. However, the strength-gain characteristics of the material should be established to fit the anticipated construction schedule and the time when the lined culvert will be returned to service. The types of materials that are typically used range from Portland cement based mortar to a controlled low strength material (CLSM).

A CLSM is usually a mixture of cement, fly ash, fine sand, and water. A typical mix may have three times more fly ash (a pozzolanic cementitious material) than cement. Hydration of the cement and slow hydration of the fly ash produces a material that may have a 28-day compressive strength of only 100 psi or 14,400 psf, which is about six times stronger than many soils that have a strength in the range of only 2,500 psf. Lower strength CLSM mixes may be used. If a CLSM-type grout mix is to be used, particularly for the first time, it is recommended that trial mixes be prepared to become familiar with the properties and procedures for mixing and handling this type of material. Example mix designs, specifications, and test methods are provided in the following Specifications section for this procedure.

It should be recognized that the slipliner must be adequately blocked or the grouting procedures must be selected to avoid displacement and/or damage to the liner during the grouting operation due to flotation. A considerable buoyant force is exerted on the lining by the fluid cement-based grout, which tends to float the liner to the top of the existing culvert. It may be noted that the buoyant force on a circular liner, in 150 pcf concrete, is approximately 1,900 pounds per lineal foot on a 4 ft. diameter liner and 8,600 pounds per lineal foot on an 8 ft. diameter liner. Thus, these forces must be resisted either by blocking or by grouting in stages so that the forces are effectively resisted by the weight of the liner. Although the buoyant force is resisted by the weight of the liner units, there is still a considerable buoyant force, which is proportionately larger with larger size culverts. The use of non-uniform and inadequate blocking can easily cause point loading, bending, and cracking of the liner.

It has been reported that the heat of hydration of portland cement based grouts may cause plastic liners to increase in length, by as much as four inches.

The National Corrugated Steel Pipe Association's "Drainage Technology Bulletin", dated September 1988, recommends that hold-down bolts be installed in the upper portion of corrugated steel liners. The hold-down devices may consist of a 3/4-inch diameter nut welded on the outside of the CMP liner pipe with a 3/4 inch diameter adjusting rod inserted. Typical spacing would be three sets on 10-foot centers longitudinally, one at the top center-line and the other two, 40 degrees to both sides. Other techniques have also been successfully used.

PROCEDURES

The first step of the grouting operation is to construct either a permanent or temporary headwall at the ends of the culvert, to block the annular space between the existing culvert and the liner. The space is then filled with the desired material by a variety of methods, depending upon the type of grout being used and various aspects of the specific project. The following discusses four of the most common techniques.

1. One method involves the installation of a temporary pipe through one or both of the end bulkheads along the top of the liner. Grout that is then pumped to the end of the pipe free-falls around the liner. It is the intent that the grout will flow completely under and around the liner and it will be consolidated by the hydrostatic head of the fluid grout. The liner may or may not be vibrated to facilitate consolidation of the grout. The pipe is slowly withdrawn so that grout may flow around the liner for the full length of the culvert. An alternate to this method of placement, which is used by at least one State, is to pour the grout through holes that are drilled through the roadway and the crown of the existing culvert.

   The biggest drawback to this procedure is that there is minimal control over placement of the grout and large voids could be created if the grout blocks up at some point. However, the grouts that are placed in this manner usually have a very high slump and are essentially self-leveling. A high cement-factor grout is used if a high strength is required and a Controlled Low Strength Material (CLSM) may be used if high strength is not required.

2. One method involves the use of grout ports that are built into the prefabricated liner sections. The ports may be just the lifting holes in the

crown of precast concrete sections or holes that are cast or built in at various elevations around the circumference of concrete and metal culvert sections. Grout that is then pumped through these ports free-falls into place around the liner.

3. Perhaps the most reliable way to place grout, to preclude the formation of voids, is to pressure grout from the bottom up. Grout is pressure injected through low level ports along both sides of the culvert liner, until it comes out of the ports at higher elevations. The grouting may be continued through the low level ports (after plugging the higher ports) or the grout placement pipe/hose may be moved to the higher level ports to minimize the pressure that is necessary to push grout uphill. Grouting is continued in this manner until the entire cavity is completely filled. This procedure, which is commonly used to grout relatively small diameter ducts for post-tensioned concrete construction, minimizes the tendency for grout to block up and create voids. This procedure is the most positive way of ensuring that the liner has good structural support.

4. A variation of the latter technique is to grout in two or three stages to minimize floatation forces on the liner. Under this procedure, the first step is inject grout through ports in the lower quadrant of the units to encase the invert and no more than the lower half of the liner. The procedure is to inject grout through ports along one side of the culvert until it comes out of the same level ports along the other side of the culvert, thereby ensuring that the entire area below the invert of the liner has been grouted. The holes are then plugged and the grout is allowed to harden before subsequent grouting is initiated.

PRECAUTIONS

1. The liner should be adequately blocked to prevent flotation and possible displacement and damage to the liner.

2. The annular space between the existing culvert and the liner should be completely filled, with no voids in the material.

3. The heat of hydration of portland cement based grouts may cause plastic pipe liners to increase in length by several inches.

4. The pressure should be monitored during pressure grouting to prevent excessive external pressure from collapsing the liner conduit.

SPECIFICATIONS

1. Suggested Guide Specifications for Flowable Fill

Texas Aggregates and Concrete Association, November 28, 1989.

GENERAL

This specification identifies the basic requirements for furnishing, mixing, and transporting flowable fill.

Flowable fill backfill material suitable for use as a structural backfill material, beneath building foundations, for filling utility trenches, excavations inside buildings, abandoned pipes and tanks, (sliplined culverts) and all routine backfilling. The material may also be used for placements in water.

MATERIALS

Materials shall conform to:

Cement - ASTM C 150
Fly Ash - ASTM C 168, class C or Class F
Water - ASTM C 94
Admixtures - ASTM C 260 and/or C 494

Fine Aggregate - Natural or manufactured sand, or a combination thereof, free from injurious amounts of salt, alkali, vegetable matter or other objectionable material. It is intended that the fine aggregate be fine enough to stay in suspension in the mortar to the extent required for proper flow. The fine aggregate shall conform to the following gradation:

Sieve Size	% Passing
3/4 inch	100
No. 200	0 - 10

MIX DESIGN

The following is given as a typical mix design for a trial mix. Adjustments of the proportions may be made to achieve proper solid suspension and optimum flowability. Admixtures may be used if desired to improve the characteristics of the mix. The suggested quantities of dry materials per cubic yard are:

Cement	100 lbs
Fly Ash	300 lbs
Fine Aggregate	2600 lbs
Water (approximate)	70 gal

CONSISTENCY

Consistency shall be tested by filling an open-ended three inch diameter cylinder six inches high to the top with flowable fill. The cylinder shall be immediately pulled straight up and the correct consistency of the flowable fill shall produce a minimum eight inch diameter circular-type spread with no segregation.

BATCHING, MIXING,AND TRANSPORTATION

Materials are to be measured by weight and/or volumetric methods. The flowable fill may be mixed in a central concrete mixer, a ready mix truck, or by other acceptable methods. The flowable fill shall be transported to the point of placement in a revolving drum mixer or in an agitator unit.

MEASUREMENT

Measurement shall be by the cubic yards delivered.

PAYMENT

Payment shall be for the measured quantity. The unit price for the flowable fill shall be full compensation for furnishing, hauling, and mixing all materials including all labor, tools, equipment, and incidentals necessary. (Note: If desired, placement of the flowable fill may also be included in this item.)

2. **Flowable Low-Strength Mortar Backfill**

"Municipal Concrete Pavement Manual - Guide Specifications and Design Standards," American Concrete Pavement Association.

Quantities of dry materials per cubic yard

Cement	100 lbs	Sand (SSD)	2800 lbs
Fly Ash	250 lbs	Water (Maximum)	500 lbs

Fine Aggregate Gradations (must stay in suspension)

Sieve Size	% Passing
3/4 inch	100
No. 200	0 - 10

3. **Supplemental Specification for Flowable Mortar**, SS 1053

Iowa Department of Transportation, January 19, 1988.

Quantities of dry materials per cubic yard

Cement	100 lbs	Sand (SSD)	2600 lbs
Fly Ash	300 lbs	Water (Maximum)	70 gal

Fine Aggregate Gradations (must stay in suspension)

Sieve Size	% Passing
3/4 inch	100
No. 200	0 - 10

RESOURCE COMMITMENT = 3:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 2:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. "Drainage Technology Bulletin," National Corrugated Steel Pipe Association, September 1988.

2. "Ready Mixed Flowable Fill," National Ready Mixed Concrete Association.

3. "Suggested Guide Specifications for Flowable Fill," Texas Aggregates and Concrete Association, 1989.

APPENDIX B-41. PROCEDURES FOR REPAIR OF MASONRY WALLS

APPLICATIONS

The following applies to the repair of stone masonry walls.

COMMENTS

The following procedure is from the cited Tennessee DOT plans(1) for rehabilitation of a stone masonry structure.

Although other procedures may be equally appropriate, the following is a workable procedure that has been used to repair a stone masonry structure. Since there are many stone masonry structures in the Tennessee highway system, the following is based on experience and has been shown to be workable and durable.

PROCEDURES

1. 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.

2. All loose soil, loose stones, loose mortar, organic or other foreign material should be removed to a minimum depth of six inches from the face of the wall.

3. Existing joints may be cleared by water jetting, but care should be taken to avoid excessive removal of existing material. Removal to a depth beyond six inches is not recommended and would require replacement with compacted mortar or a combination of stone and compacted mortar.

4. The resulting voided areas should be repaired by a mortar filling to within one-half inch of the vertical wall surface. Mortar should be tinted to match the color of the stone used in the structure.

5. Mortar should be of a stiff consistency (essentially zero slump) and should be ram packed into voids and joints. Mortar for repairs and repointing of stones should conform to agency specifications.

6. 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. It should be free from seams, cracks, structural defects, and imperfections tending to reduce its resistance to weathering. It should 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 their respective thicknesses. Lengths should not be less than 1-1/2 times their respective widths.

7. 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. Mortaring should not be performed in freezing weather. Any work damaged by frost should be removed and replaced.

RESOURCE COMMITMENT = 1:	5	4	3	2	1
	Heavy		Medium		Low
COST RELATIVE TO REPLACEMENT = 1:	5	4	3	2	1
	High		Medium		Low

REFERENCES

1. "Plans for Rehabilitation of Coward Mill Road Bridge over Beaver creek, Knox County, Tennessee DOT, 1989.

APPENDIX B-42. PROCEDURES FOR JACKING CONCRETE PIPE

APPLICATIONS

The process of tunneling and jacking may be used to install reinforced concrete pipe with diameters ranging from as low as 18-inch to as great as 132-inch.

COMMENTS

The process of tunneling and jacking was first used by the Northern Pacific Railroad between 1896 and 1900. Since that time, it has become widely used, particularly where deep excavations are necessary or where conventional open excavation and backfill methods may not be feasible. It is also being used to install replacement or larger culverts under highways. Although it is possible to install pipes as small as 18 inches in diameter, the normal minimum is 36 inches because the normal procedures require that workmen have access through the pipe to the heading. When smaller pipes are installed by jacking, the earth is removed by mechanical equipment such as augers and boring equipment.

During the excavation, material is removed so that the tunnel bore is slightly larger than the outside diameter of the pipe; this results in minimal disturbance to the adjacent soil above and beside the pipe. The lead pipe is generally contained inside a shield which projects from the mining machine or it is equipped with a cutter or shoe to protect the pipe when excavation is done by hand. It is desirable that the jacking be done in a continuous operation because, if forward movement is stopped, the pipe tends to set or freeze, which then creates considerable frictional resistance to subsequent jacking forces.

Two types of loads are imposed on pipe installed by the jacking method: the axial load due to the hydraulic jacks, and earth loading due to overburden, which generally becomes effective only after the installation is complete. The axial or thrust jacking loads are transmitted from one concrete pipe section to another through the joint surfaces. 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. For long pipelines and culverts, it may be necessary to establish intermediate jacking stations, so that predetermined jacking forces will not be exceeded. Little or no gain in axial crushing resistance is provided by specifying a higher class of pipe.

PROCEDURES

A typical equipment setup for jacking concrete pipe is shown in figure B.42.1. A general procedure for jacking concrete pipe is illustrated in figure B.42.2. The usual construction sequence for tunneling and jacking concrete pipe is:

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

Pits are excavated on each side. The jack will bear against the back of the left pit so a steel or wooden abutment is added for reinforcement. A simple track is added to guide the concrete pipe sections. The jacks are positioned in place on supports.

A section of concrete pipe is lowered into the pit.

The jacks are operated pushing the pipe section forward.

The jack rams are retracted and a "spacer" is added between the jacks and pipe.

The jacks are operated and the pipe is pushed forward again.

It may be necessary to repeat the above steps four and five several times until the pipe pushed forward enough to allow room for the next section of pipe. it is extremely important, therefore, that the stroke of the jack be as long as possible to reduce the number of spacers required and thereby reduce the amount of time and cost. The ideal situation would be to have the jack stroke longer than the pipe to completely eliminate the need for spacers.

The next section of pipe is lowered into the pit and the above steps repeated. The entire process above is repeated until the operation is complete.

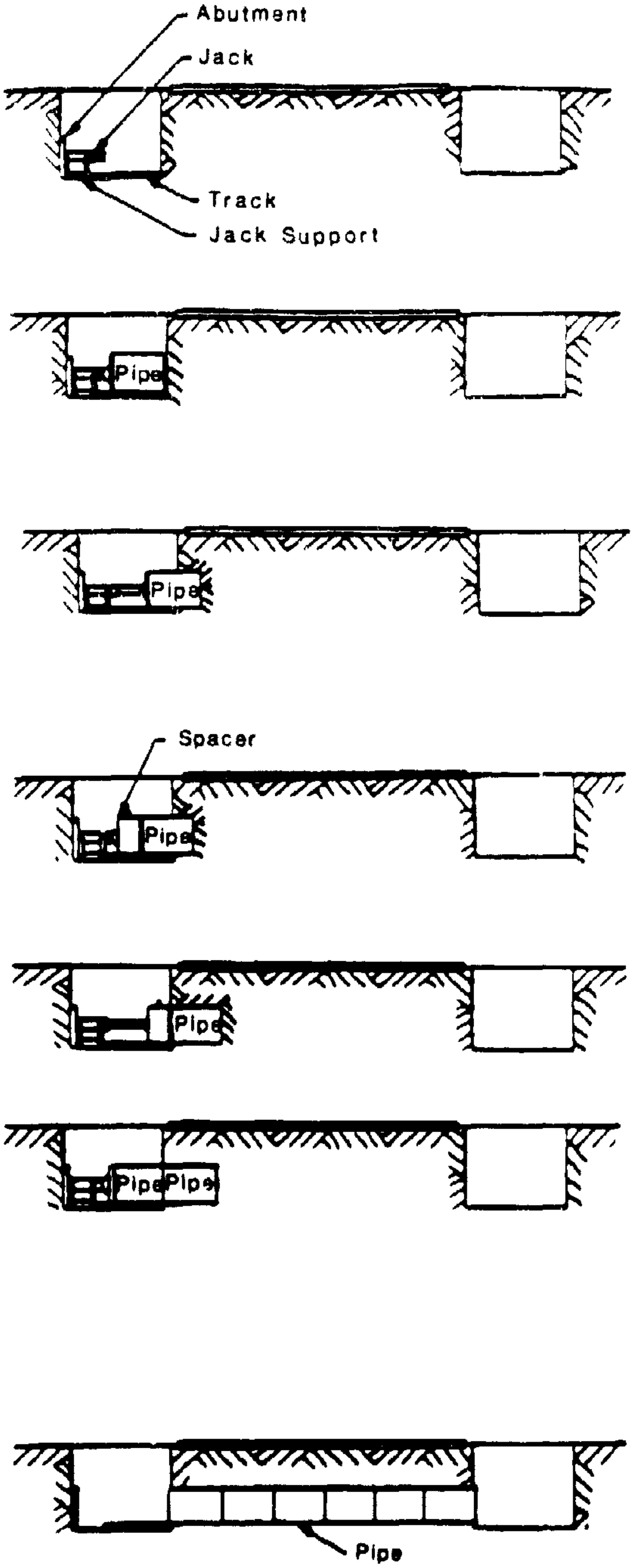


Figure B.42.1. General procedures for jacking concrete pipe.[1]

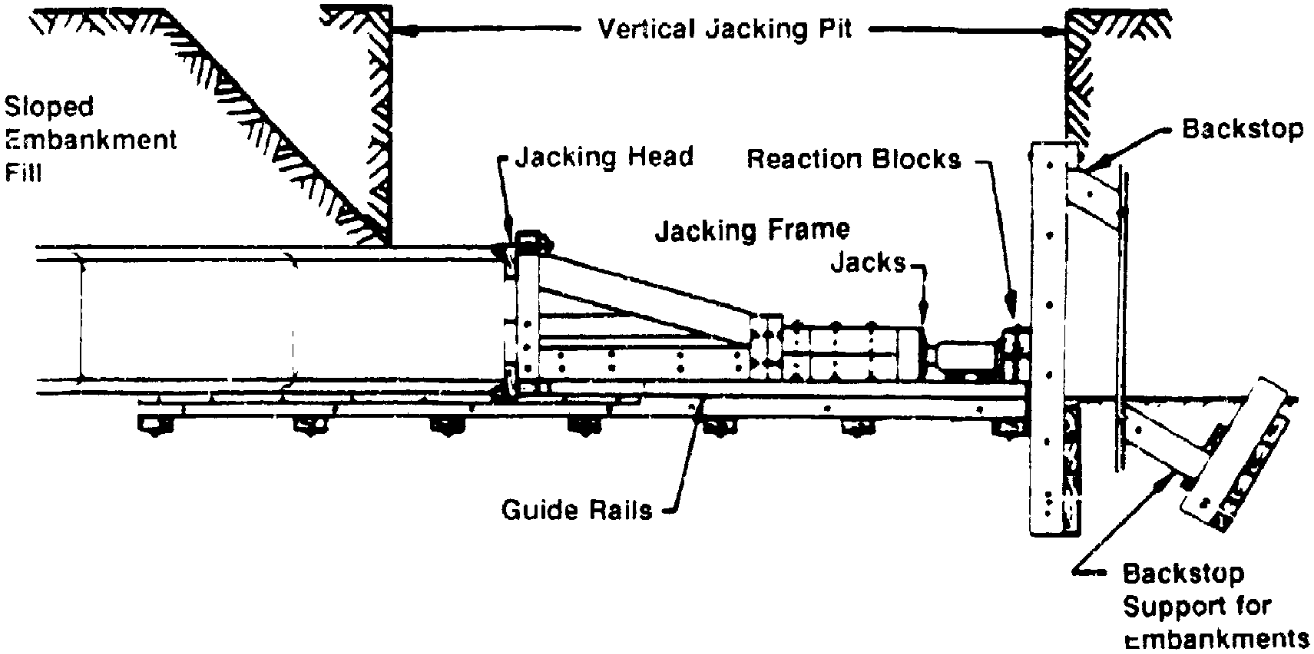


Figure B.42.2. Typical equipment setup for concrete pipe jacking.(1)

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

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

4. Continue excavation, remove soil through pipe, insert succeeding sections of pipe between lead pipe and jacks and jack forward.

5. Repeat sequence, excavation, soil removal, pipe insertion and jacking, until the operation is complete.

PRECAUTIONS

Care should be given to personnel safety. Heavy pressures are exerted by hydraulic jacks, which can cause breakage of materials. Hydraulic hose lines may rupture and cause injury.

RESOURCE COMMITMENT = 3:	5 Heavy	4	3 Medium	2	1 Low
COST RELATIVE TO REPLACEMENT = 3:	5 High	4	3 Medium	2	1 Low

REFERENCES

1. *Concrete Pipe Handbook*, American Concrete Pipe Association, 1988.

2. "Design Data 13," American Concrete Pipe Association, July 1969.

APPENDIX C. SPECIFICATIONS AND DESIGN PROCEDURES

APPENDIX C-1. SPECIFICATION GUIDE FOR EROSION CONTROL GEOTEXTILES

TASK FORCE 25 SPECIFICATION GUIDES
JOINT COMMITTEE ON NEW MATERIALS, AASHTO

1. DESCRIPTION

1.1 This work shall consist of furnishing and placing a geotextile for the following drainage applications: cut and fill slope protection, protection of various small drainage structures and ditches, wave protection for causeways and shoreline roadway embankments, and scour protection for structures such as bridge piers and abutments. The geotextile shall be designed to allow passage of water while retaining insitu soil without clogging. The quantities of erosion control geotextiles as shown on the plans may be increased or decreased at the direction of the engineer based on construction procedures and actual site conditions that occur during construction of the project. Such variations in quantity will not be considered as alterations in the details of construction or a change in the character of the work.

2. MATERIALS

2.1 Fibers used in the manufacture of geotextiles, and the threads used in joining geotextiles by sewing, shall consist of long chain synthetic polymers composed of at least 85% by weight polyolefins, polyesters, or polyamides. They shall be formed into a network such that the filaments or yarns retain dimensional stability relative to each other, including selvages. These materials shall conform to the physical requirements of table B.7.2.

2.2 Geotextile rolls shall be furnished with suitable wrapping for protection against moisture and extended ultraviolet exposure prior to placement. Each roll shall be labeled or tagged to provide product identification sufficient for inventory and quality control purposes. Rolls shall be stored in a manner which protects them from the elements. If stored outdoors, they shall be elevated and protected with a waterproof cover.

3. CONSTRUCTION REQUIREMENTS

3.1 **Geotextile Exposure Following Placement**. Exposure of geotextiles to the elements between laydown and cover shall be a maximum of fourteen (14) days to minimize damage potential.

3.2 **Erosion Control Placement**. The geotextile shall be placed and anchored on a smooth graded surface approved by the engineer. The geotextile shall be placed in such a manner that placement of the overlying materials will not excessively stretch or tear the fabric. Anchoring of the terminal ends of the geotextile shall be accomplished through the use of key trenches or aprons at the crest and the toe of the slope (refer to figures B.7.5 through B.7.8.).[NOTE: In certain applications to expedite construction, 18-inch long anchoring pins, placed on 2 to 6 feet centers, depending on the slope of the covered area, have been used successfully.]

3.2.1 **Slope Protection Placement**. Successive geotextile sheets shall be overlapped in such a manner that the upstream sheet is placed over the downstream sheet and/or upslope over downslope. In underwater applications, the geotextile and required thickness of backfill material shall be placed the same day. The backfill placement shall begin at the toe and proceed up the slope.

Riprap and heavy stone filling shall not be dropped onto the geotextile from a height of more than one foot. Slope protection and smaller sizes of stone filling shall not be dropped onto the geotextile from a height exceeding three feet. Any geotextile damaged during placement shall be replaced as directed by the engineer at the Contractor's expense.

3.3 **Seams**. The geotextile shall be joined by either sewing or overlapping. All seams shall be subject to the approval of the Engineer. Overlapped seams shall have a minimum overlap of 12 inches except when placed under water where the overlap shall be a minimum of three feet.

3.4 **Repair**. A geotextile patch shall be placed over the damaged area and extend three (3) feet beyond the perimeter of the tear or damage.

4. METHOD OF MEASUREMENT

4.1 The geotextile shall be measured by the number of square yards computed from the payment lines shown on the plans or from payment lines established in writing by the Engineer. This excludes seam overlaps, but shall include geotextiles used in the crest and the toe of slope treatments.

4.2 Slope preparation, excavation and backfill, bedding, and cover material are separate pay items.

5. BASIS OF PAYMENT

5.1 The accepted quantities of geotextile shall be paid for at the contract unit price per square yard in place.

5.2 Payment will be made under:

PAY ITEM	PAY UNIT
Erosion Control Geotextile	Square Yard

TABLE 1
PHYSICAL REQUIREMENTS [1,2]
FOR EROSION CONTROL GEOTEXTILES

	EROSION CONTROL [3]		
PROPERTY	CLASS A[4]	CLASS B[5]	TEST METHOD
Grab Strength Lbs.	200	90	ASTM D 4632
Elongation (%)	15	15	ASTM D 4632
Sewn Seam Strength[6] Lbs.	180	80	ASTM D 4632
Puncture Strength Lbs.	80	40	ASTM D 4833
Burst Strength psi	320	140	ASTM D 3786
Trapezoid Tear Lbs.	50	30	ASTM D 4533
Apparent Opening Size	1. Soil with 50% or less particles by weight passing U.S. No. 200 Sieve, AOS less than 0.6mm (greater than #30 U.S. Std. Sieve) 2. Soil with more than 50% particles by weight passing U.S. No. 200 Sieve, AOS less than 0.297mm (greater than #50 U.S. Std. Sieve)		ASTM D 4751
Permeability[7] (cm/sec)	k fabric >k soil for all classes		ASTM D 4491
Ultraviolet Degradation at 150 hours	70% Strength retained for all classes		ASTM D 4355

[1] Acceptance of geotextile material shall be based on ASTM D 4759.

[2] Contracting agency may require a letter from the supplier certifying that its geotextile meets specification requirements.

[3] Minimum. Use value in weaker principal direction. All numerical values represent minimum average roll value (i.e., test results from any ampled roll in a lot shall meet or exceed the minimum values in the Table). Stated values are for non-critical, non-severe applications. Lots sampled according to ASTM D 4354.

[4] Class A Erosion Control applications are those where fabrics are used under conditions where installation stresses are more severe than Class B applications; i.e., stone placement height should be less than 3 feet and stone weights should not exceed 250 pounds.

[5] Class B Erosion Control applications are those where fabric is used in structures or under conditions where the fabric is protected by a sand cushion or by "zero drop height" placement of stone.

[6] Values apply to both field and manufactured seams.

[7] A nominal coefficient of permeability may be determined by multiplying permittivity value by nominal thickness. The k value of the fabric should be greater than the k value of the soil.

APPENDIX C-2. RIPRAP DESIGN IN CHANNELS

The design method described below is adapted from *Design of Roadside Channels with Flexible Linings*, Hydraulic Engineering Circular No. 15(1) of the Federal Highway Administration. It is applicable to both straight and curved sections of channel where the flow is tangent to the bank of the channel. This condensed methodology was taken from the Virginia Erosion and Sediment Control Handbook.(2)

Tangent Flow - Federal Highway Administration Method

This design metnod determines a stable rock size for straight and curved sections of channels. It is assumed that the shape, depth of flow, and slope of the channel are known. A stone size is chosen for the maximum depth of flow. If the sides of the channel are steeper than 3:1, the stone size must be modified accordingly. The final design size will be stable on both sides of the channel and the bottom.

1. Enter Figure 1 with the maximum depth of flow (feet) and channel slop (feet/foot). Where the two lines intersect, choose the d_{50} for the diagonal line above the point of intersection).

2. If channel side slopes are steeper than 3:1, continue with step 3, if not, the procedure is complete.

3. Enter Figure 2 with the side slope and the base width to maximum depth ratio (B/d). Where the two lines intersect, move horizontally left to read K_1.

4. Determine from Figure 3 the angle of repose for the d_{50} size of stone and the side slope of the channel. (Use 42° for d_{50} greater than 1.0±. Do not use riprap on slopes steeper than the angle of repose for the size of stone).

5. Enter Figure 4 with the side slope of the channel and the angle of repose for the d_{50} size of stone. Where the two lines intersect, move vertically down to read K_2.

6. Compute $d_{50} \times K_1/K_2 = d'_{50}$ to determine the correct size stone for the bottom and side slopes of straight sections of channel.

For Curved Sections of Channel

1. Compute the radius of the curve (Ro), measured a the outside edge of the bottom.

2. Computer the ratio of the top width of the water surface (Bs) to the radius of the curve (Ro), Bs/Ro.

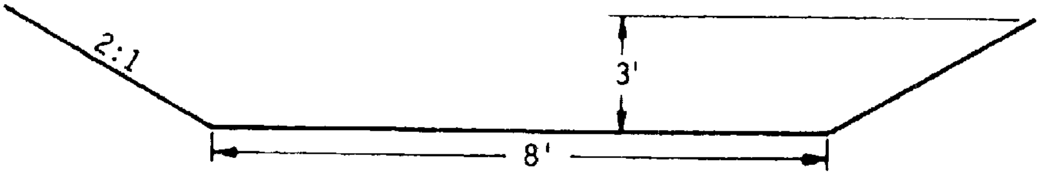
3. Enter Figure 5 with the ratio Bs/Ro. Move vertically until the curve is intersected. Move horizontally left to read K_3.

4. Compute d'_{5} x K_{50r} to determine the correct size stone for bottom and side slo of curved sections of channel.

Example Problem

Given:

A trapezoidal channel 3 feet deep, 8 feet bottom, 2:1 side slopes, and a 2% slope.



Calculate:

A stable riprap size for the bottom and side slopes of the channel.

Solution

1. From Figure 1, for a 3-foot-deep channel on a 2% grade, d_{50} = 0.75 feet or 9 inches.

2. Since the side slopes are steeper than 3:1, continue with step 3.

3. From Figure 2, B/d= 8/3 2.67, Z= 2, K_1 = 0.82.

4. From Figure 3, for d_{50} = 9 inches, ϕ = 41°.

5. From Figure 4, for Z= 2 and ϕ = 41°, K_2 = 0.73.

6. $d_{50} \times K_1/K_2 = d_{50} = 0.75 \times 0.82/0.73 = 0.84$ feet.

   $0.84 \text{ feet} \times \frac{12 \text{ inches}}{1 \text{ foot}} = 10.08$ Use d'_{50} = 10 inches.

Given:

The preceding channel has a curved section with a radius of 50 feet.

Calculate:

A stable riprap size for the bottom and side slopes of the curved section of channel.

Solution:

1. Ro = 50 feet
2. Bs/Ro = 20/50 = 0.40
3. From Figure 5, for Bs/Ro = 0.40, K_3 = 1.1
4. $d'_{50} \times K_3 = d_{50c} = 0.84 \times 1.1 = 0.92$ feet

$$0.92 \text{ feet} \times \frac{12 \text{ inches}}{1 \text{ foot}} = 11.0 \text{ inches}$$

REFERENCE

1. *Design of Roadside Channels with Flexible Linings*, Hydraulic Engineering Circular No. 15, FHWA-IP-87-7. US Department of Transportation, Federal Highway Administration, McLean, Virginia, April 1988.

2. *Virginia Erosion and Sediment Control Handbook*, Virginia Department of Conservation and Historic Resources, Division of Soil and Water Conservation, Richmond, VA, 1980.

3. *Drainage Manual*, Virginia Department of Highways and Transportation, Location and Design Division, Hydraulics Section, Richmond, VA, January 1980.

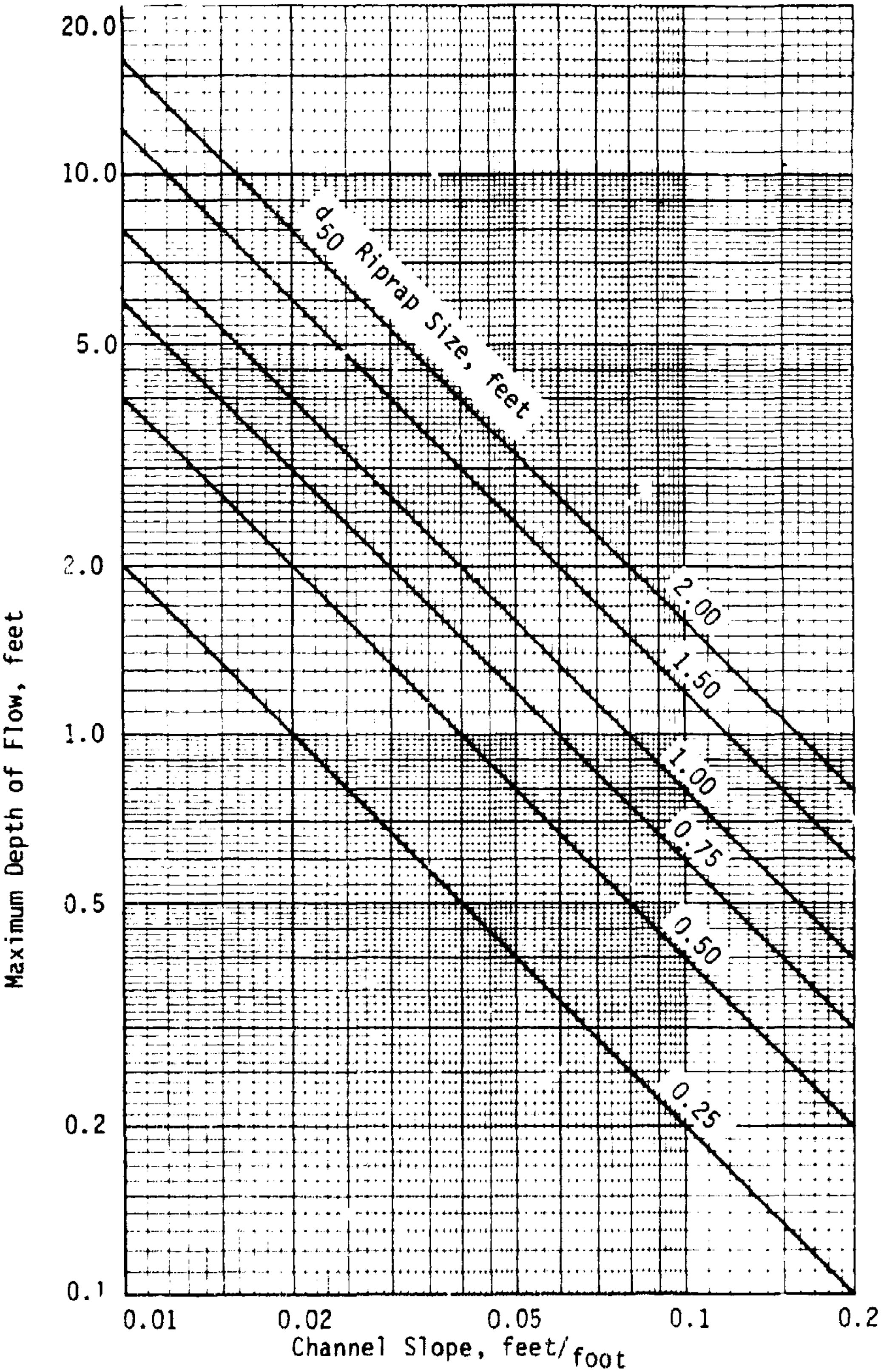


Figure C.2.1. Maximum depth of flow for riprap-lined channels.(3)

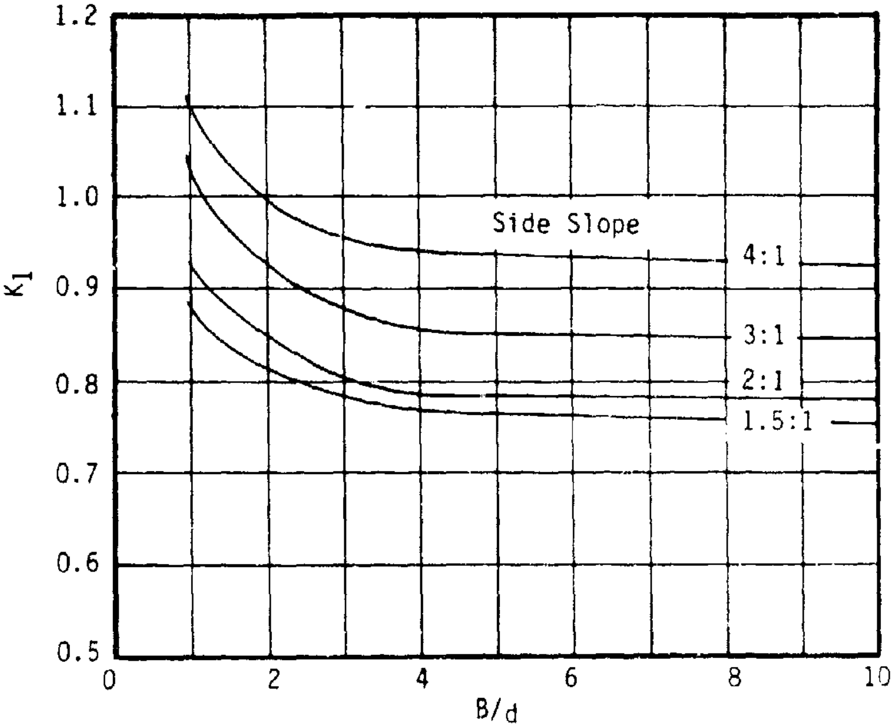


Figure C.2.2. Distribution of boundary shear around wetted perimeter of trapezoidal channel.[3]

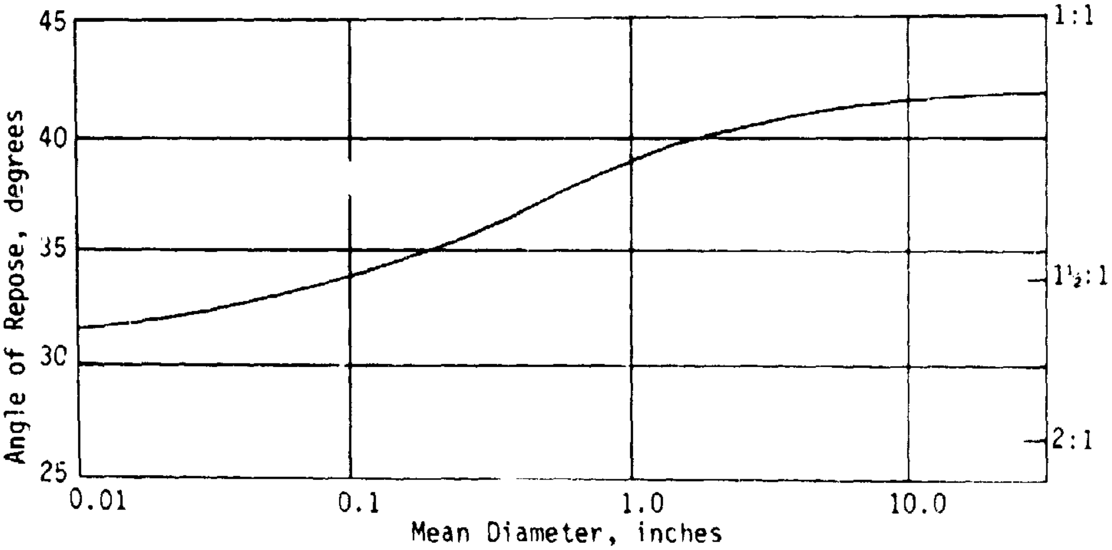


Figure C.2.3. Angle of repose for riprap stones.[3]

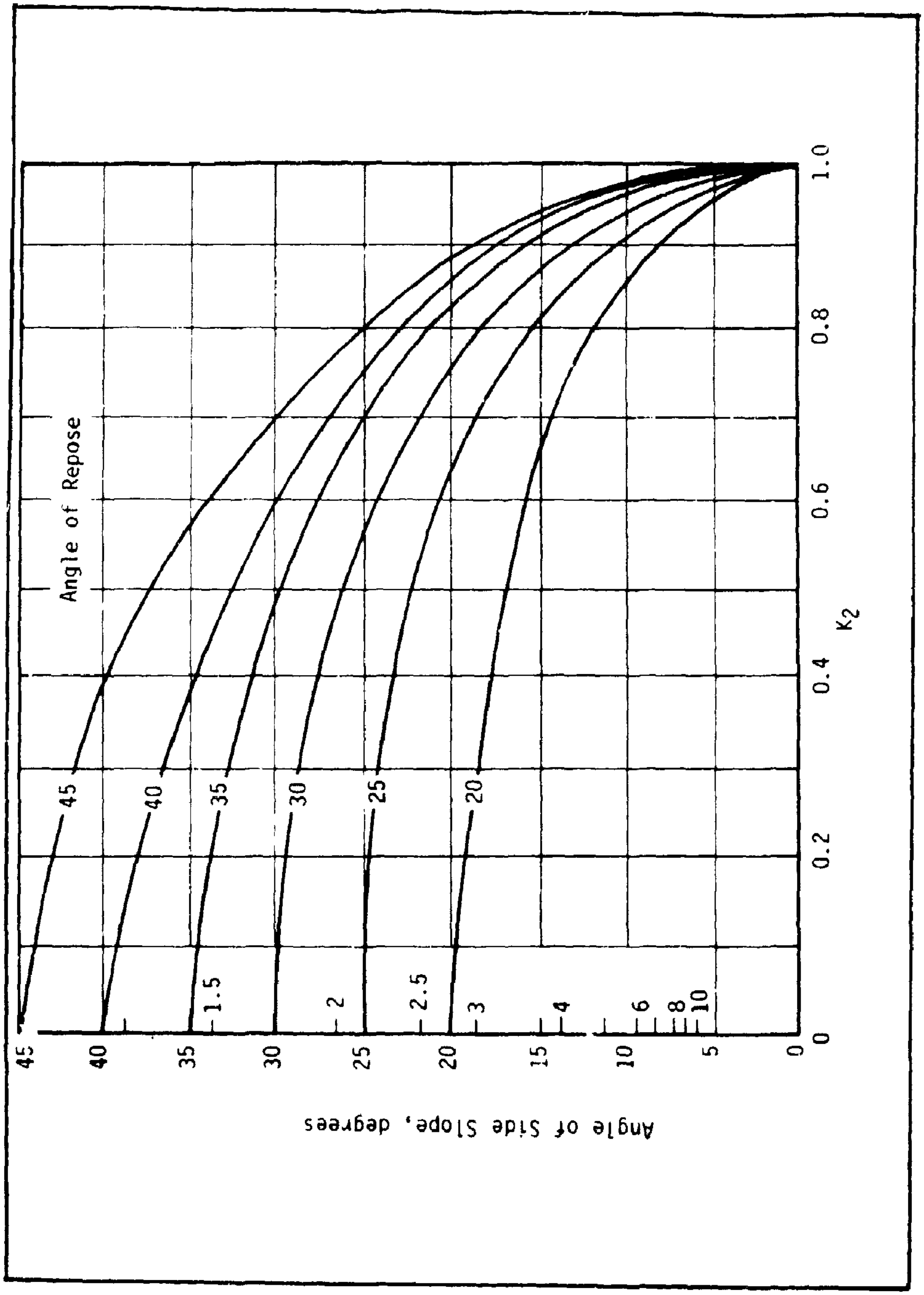


Figure C.2.4. Ratio of critical shear on sides to critical shear on bottom.[3]

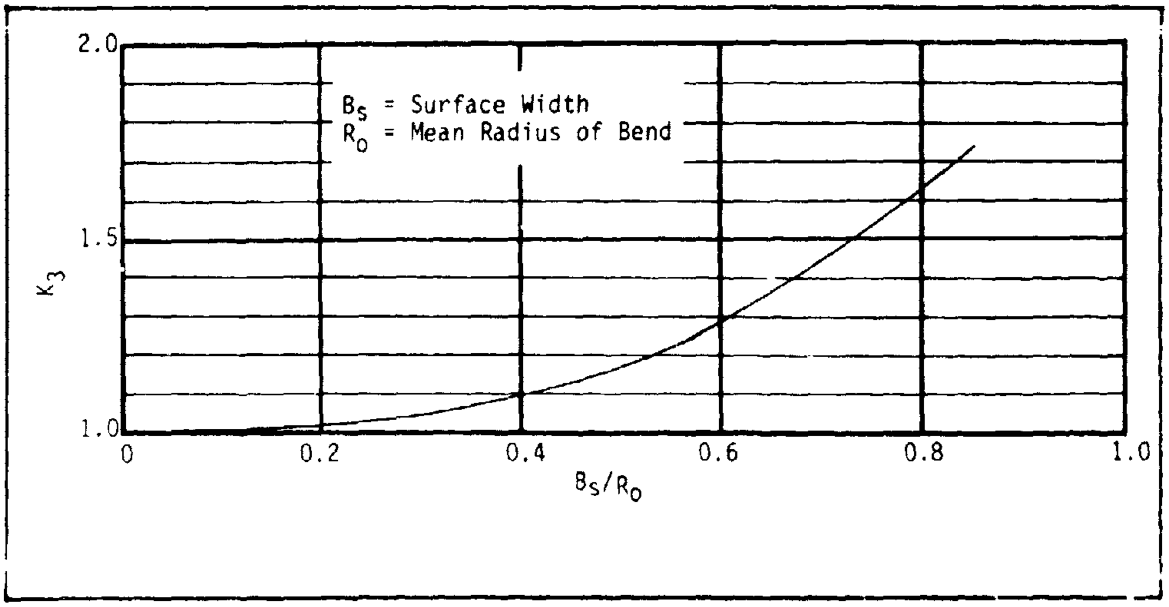


Figure C.2.5. Ratio of maximum boundary shear in bends to maximum bottom shear in straight reaches.(3)

APPENDIX D. SOURCES OF INFORMATION AND ASSISTANCE

APPENDIX D. SOURCES OF INFORMATION AND ASSISTANCE

PIPE & CULVERT PRODUCER ASSOCIATIONS

American Concrete Pipe Association
8300 Boone Blvd., Suite 400
Vienna, Virginia 22182
PHONE: (703) 821-1990
FAX: (703) 821-3054

Fiberglass Pipe Institute
(A Division of The Society of the Plastics Industry, Inc.)
355 Lexington Avenue
New York, New York 10017
PHONE: (212) 351-5413

National Corrugated Steel Pipe Association
Fifth Floor, 2011 Eye Street, N.W.
Washington, D.C. 20006
PHONE: (202) 223-2217
FAX: (202) 457-9121

Plastic Pipe Institute
(A division of The Society of the Plastics Industry, Inc.)
355 Lexington Avenue
New York, New York 10017
PHONE: (212) 351-5420

The Society of the Plastics Industry
1275 K Street, NW, Suite 400
Washington, D.C. 20005
PHONE: (202) 371-5200

Uni-Bell PVC Pipe Association
2655 Villa Creek Drive, Suite 155
Dallas, Texas

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Detroit, Michigan 48219
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FAX: (313) 538-0655

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PHONE: (312) 670-2400

American Iron & Steel Institute
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Washington, D.C. 20005
PHONE: (202) 452-7100

American Society for Testing and Materials
1916 Race Street
Philadelphia, Pennsylvania 19103-1187
PHONE: (215) 299-5400
FAX: (215) 977-9679

International Association of Concrete Repair Specialists
P.O. Box 17402
Dulles International Airport
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National Ready Mix Concrete Association
900 Spring Street
Silver Spring, Maryland 20910
PHONE: (301) 587-1400

Portland Cement Association
5420 Old Orchard Road
Skokie, Illinois 60077
PHONE: (708) 966-6200

Texas Aggregate & Concrete Association
6633 Highway 290 East, Suite 100
Austin, Texas 78723
PHONE: (512) 451-5100

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444 North Capital Street, Suite 225
Washington, D.C. 20001
PHONE: (202) 624-5800

American Railway Engineering Association
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Washington, D.C. 20001
PHONE: (202) 639-2190

National Association of County Engineers
326 Pike Road
Ottumwa, Iowa 52501
PHONE: (515) 684-6928

Transportation Research Board
2101 Constitution Avenue, N.W.
Washington, D.C. 20418
PHONE: (202) 334-2934

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FAX: (918) 622-7353

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Columbus, Ohio 43221
PHONE: (614) 457-3051
FAX: (614) 459-0169

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Richardson, Texas 75083
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1050 Busse Highway
Suite 200
Bensenville, Illinois 60106
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FAX: (406) 248-2196

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PHONE: (901) 363-2105
FAX: (901) 365-3906

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FAX: (416) 886-7323

Miller Pipeline Corp.
XPANDIT
P.O. Box 34141
Indianapolis, Indiana 46234
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3M Center
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Minneapolis, Minnesota 55435
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P.O. Box 238
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McLean, Virginia 22102
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850 Avenue H East
Arlington, Texas, 76011
PHONE: (817) 640-1555
FAX: (817) 649-7816

APPENDIX E. ANNOTATED BIBLIOGRAPHY

AASHTO Maintenance Manual, 1987. American Association of State Highway and Transportaton Officials, Washington D.C., 1987.

The manual contains a chapter on drainage which briefly discusses culverts. However, it is very general but recommends cleaning and the removal of obstructions.

Abt, S. R., J. F. Ruff, F. K. Doehring, and C. A. Donnell. "Influence of Culvert Shape on Outlet Scour." Journal of Hydraulic Engineering, Vol. 113, No. 3, ASCE, New York, N.Y., March 1987, pp. 393-400.

This paper reports on the results of investigation on scour hole dimensions of square, arch and rectangular culvert shapes compared to circular shape. Scour geometry at culvert outlets is used to determine the need for potential erosion protection.

"Air-inflated forms speed Florida culverts." Roads & Bridges, November 1987, p. 20.

Article discusses use of air-inflated form system from Concepts in Concrete Inc. on job in Florida for a privately funded road upgrade for a shopping center.

"Aluminum Culvert Replaces Bridge in Indiana." Better Roads, Vol. 57, No. 6, June 1987, p. 56.

Article discusses use of corrugated aluminum box culverts for bridge replacement in Blackford County, Indiana. Culvert installed was 25.5 feet wide x 12 feet high by 26 feet long and was fabricated at Kaiser Aluminum and Chemical Corporation's Mitchell, Indiana drainage products plant.

Arnoult, James D. "Culvert Inspection Manual: Supplement to the Bridge Inspector's Training Manual." Report No. FHWA-IP-86-2, Federal Highway Administration, McLean, VA, July 1986.

Manual provides guidelines for the inspection and evaluation of existing culverts. It is a stand alone supplement to the Bridge Inspector's Training Manual.

Boadsgaard, Marinus and Punda Pai. "Sewer Line Rehabilitation Without Excavation." Public Works, Vol. 119, No. 10, September 1988, p. 93.

Describes project in Clark County, Nevada, Sanitation District to repair 2 1/2 mile section of sewer line which deteriorated from sulfide corrosion. District investigated and selected INSITUFORM which had never been previously used in Nevada.

Bealey, Mike, "Precast Concrete Pipe Durability: State of the Art." TRR 1001, TRB, Washington, D.C., 1984, p. 88.

The performance of precast concrete pipe is reviewed, and state-of-the-art information concerning the durability of buried precast concrete pipe is presented. The article concludes that service life of precast concrete pipe in most installation environments is virtually unlimited.

Beucler, Brian. "Pipe Rehabilitation on Skyline Drive, Shenandoah National Park." Experimental Projects Program Report, Office of Highway Operations Demonstration Projects Division, FHWA, Washington, D.C., undated report.

Paper discusses the rehabilitation of culverts on the Skyline Drive. There are hundreds of 50 year old damaged concrete and corrugated metal pipes underneath the roadway. The "Insituform" method of repair was selected. The methods for comparing Insituform with pipe replacement are presented.

Blonska, Frank ed., "Condition and Corrosion Survey on Corrugated Steel Storm Sewer and Culvert Pipe." Interim Report prepared for the National Corrugated Steel Pipe Association, Washington, D.C., February 1987.

Reports on a detailed inspection and testing program sponsored by NCSPA to evaluate the long term performance of corrugated steel pipe throughout the U.S.

"Bridge Alert: Air-Inflated Form Ideal for Culverts." Better Roads, Vol. 57, No. 5, May 1987, p. 40.

Article describes use of "Air-O-Form" which was developed for small concrete tanks and earth shelter homes and adopted by inventor, Gene Hale, for arch bridges and utility structures.

"Bridge Alert: Innovative Techniques And Bridge Projects." Better Roads, Vol. 57, No. 5, May 1987, p. 37.

One section of article discusses use of precast concrete culvert for a small bridge replacement. The arch box shape was developed and patented by Lockwood, Jones and Beals for Con/Span Culvert Systems. First installation was in Butler County, Ohio.

Byrd, Gary and George Briggs. Street and Highway Maintenance Manual. American Public Works Association, 1985, pp. 137-139.

Contains brief description of culvert maintenance. It recommends cleaning and debris removal and recommends different basic repairs depending on conditions.

"Case History No. 5, Culvert Relining Australia." Undated section of Rib Loc Brochure forwarded by Mr. A. J. Sutton, Rib Loc Group Limited, The Levels, South Australia, Australia, November 15, 1988.

Briefly describes use of Rib-Loc material as a "former" for the structural repair of a corrugated metal pipe under an Australian National Railways roadbed.

Chambers, R. E., T. J. McGrath and F. J. Heger. "Plastic Pipe for Subsurface Drainage of Transportation Facilities." National Cooperative Highway Research Program Report 225, TRB, Washington, D.C., October 1980.

Report summarizes the results of a study of buried plastic pipe for the drainage of transportation facilities. The report does not consider in detail but mentions that PE gravity or force main sewer pipe may be appropriate for storm drains and culverts, reinforced plastic mortar (RPM) pipe may be used for storm drains and culverts and large diameter corrugated PE tubing may be useful for small secondary culverts.

Clarkson, T. E. and J. C. Thomson. "Pipe Jacking: State of the Art in U.K. and Europe." Journal of Transportation Engineering, Vol. 109, No. 1, American Society of Civil Engineers, New York, N.Y. Jan 1983, pp. 57-72.

Article discusses the development of pipe and box jacking techniques in the U.K. and Europe. A good description of pipe jacking equipment and procedures is included. The different types of concrete pipe joints used in U.K., Germany and France are shown.

Cowherd, D. C., G. H. Degler. "Evaluation of Long-Span Corrugated Metal Structures." FHWA/OH-86/011, Ohio Department of Transportation, Columbus, Ohio, May 1986.

This report describes the field evaluation of 17 long-span corrugated metal structures which had span dimensions from 20 feet to 31 feet and rises from 7 feet 9 inches to 19 feet 3 inches and lengths of 44 feet to 148 feet. The evaluation also had as an objective the development of a computer program to evaluate these structures and then to analyze the structure movement. The descriptions of the culverts and recommended actions are good.

Crumpton, Carl F., Glen M. Koonty, and Barbara J. Smith. "For Want of Air, a Drainage System Was Nearly Lost." TRR 1001, TRB, Washington, D.C., 1984, p. 94.

The omission of air entrainment from a concrete pipe end section in 1972 set up a chain of events that could have been much more destructive.

"Culvert Design Systems." FHWA-TS-80-245, Wyoming State Highway Department,
Hydraulics Section, U.S. Department of Transportation, Washington, D.C., December 1980.

Program documentation to hydraulically design a culvert or hydraulically review an existing or proposed culvert size. The paper is highly technical and may be somewhat obsolete.

"Culvert Maintenance and Replacement." American Railway Bridge and Building Association, Homewood, Illinois, 1982.

Brief descriptions of railroad culvert problems, repairs and replacements.

Drennon, Clarence B. "Pipe Jacking: State-of-the-Art." Journal of the Construction Division, Vol. 105, No. C03, American Society of Civil Engineers, New York, N.Y., Sept. 1979, pp. 217-223.

Pipe jacking is a method of producing tunnels by placement of a precast reinforced final liner immediately behind the excavation by pushing the lines in sections with hydraulic jacks from a shaft. It is used in the U.S. for circular tunnels from 54 inch to 102 inch. A very good, practical description of pipe jacking.

Driver, F. T. and M. R. Olson. *Demonstration of Sewer Relining by the Insituform Process, Northbrook, Illinois*. EPA-600/2-83-064, Municipal Environmental Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Cincinnati, Ohio, October 1983.

Report was initiated to determine the effectiveness of a new process of lining sewers called Insituform. Two test sections of sewer in need of rehabilitation were lined to evaluate the effectiveness of the lines in eliminating infiltration and the effect on flow characteristics. The study documents the fact that the method is an effective process for eliminating infiltration from lines and improves the hydraulics and structural integrity of damaged conduits.

Duncan, Charles R. "Innovated Repair of a Large Failing Structural Steel Plate Pipe Arch Culvert." *TRR 1001*, TRB, Washington, D.C., 1984, p. 98.

This paper discusses a project where a value-engineering team studied alternatives to replacing a structural steel plate pipe arch culvert 14 feet x 9 feet 8 inch x 260 feet long. The team's proposal consisted of rolling a slightly smaller asbestos-bonded asphalt-coated pipe through the existing culvert and grouting between them.

Duncan, J. M., R. B. Seed and R. H. Drawsky. "Design of Corrugated Metal Box Culverts." *TRR 1008*, TRB, Washington, D.C., 1985, p. 33.

The procedure encompasses bending mements in the crown and haunch sections due to backfill and traffic loads, design of portland cement concrete relieving slabs for conditions where cover depth is severely limited, recommended load factors for design, and deflections in service for metal box culverts with spans as large as 26 ft.

Durability of Drainage Pipe. NCHRP Synthesis of Highway Practice 50, TRB, Washington, D.C., 1978.

This report deals with material durability or the ability of drainage pipe to endure corrosion and abrasion. It does not address structural durability. The report contains summaries of field and laboratory studies carried out in half of the states. It recommends that guidelines for selection of pipe materials should be developed or modified based on local conditions. The report gives descriptions of corrosion and abrasion, ranges of values and their effects on the various materials used in culverts. There are good chapters on pipe protective measures, maintenance and repair of culverts, and service life estimation.

Etti-Williams, Jimmy L. "The Performance of Corrugated Metal Culvert Pipes." Report of Research Division, Oklahoma DOT, Oklahoma City, Oklahoma, June 1988.

Report describes work by ODOT research engineers to develop efficient and cost effective method of repairing deteriorated CMP. The methods discussed are placing cement grouts in the perforated invert and placing a polythyelene inner liner.

Evans, Willis A. and Beryl Johnston. "Fish Migration and Fish Passage, A Practical Guide to Solving Fish Passage Problems." USDA Forest Service, Washington, D.C., June 1972, revised June 1980.

This guide was prepared by members of the Region 5 staff (California) but has a good general discussion of fish passage requirements and considerations. It contains a section on investigating new culverts, installing baffles in culverts, and inspection and correction of existing culverts.

Existing Sewer Evaluation and Rehabilitation. ASCE Manuals and Reports on Engineering Practice No. 62, WPCF Manual on Practice No. FD-6, Prepared by a Joint Task Force of ASCE and WPCF, American Society of Civil Engineers, New York, N.Y. and Water Pollution Control Federation, Washington, D.C., 1983.

This manual provides guidelines for the evaluation and rehabilitation of sanitary sewer. The major emphasis of the manual is on infiltration and inflow reduction. It contains sections on pipeline rehabilitation and materials which are generally applicable to culverts.

A Guide to Standardized Highway Drainage Products. AASHTO-AGC-ARTBA Joint Cooperation Committee, Subcommittee on New Highway Materials, Task Force, No. 13, Washington, D.C., Dec. 1986.

This guide presents drawings of currently available common drainage products.

Heummen, P. H. Van. "Half-Century Experience with Precast Reinforced-Concrete Box Sections for Culverts and Storm Drains in the Netherlands." TRR 1001, TRB, Washington, D.C., 1984, p. 112.

Under varying aggressive conditions, there are tens of thousands of culverts and other structures that make up a system of water control in the Netherlands. Most of these culverts have been constructed in precast reinforced-concrete box sections. The real service life, even under severe conditions, amply meets the design service life.

Hill, James J. "Construction and Evaluation of Precast Concrete Arch Structures." TRR 1008, TRB, Washington, D.C., 1985, p. 94.

Information is given regarding the durability of concrete pipe used for culverts at acidic flow sites (pH less than 7.0) in the state of Ohio. In general, unprotected concrete pipe will provide adequate service life (50 years or more) except at extremely acidic sites (pH less than 4.5).

Hill, James J. and Arunprakash M. Shirole. "Comparative Evaluation of Precast Concrete Pipe-Arch and Arch Structures." TRR 1087, TRB, Washington, D.C., 1986, p. 32.

A comparative evaluation of precast concrete pipe-arch and arch structures constructed in Minnesota during the past 20 years is presented. Comparative evaluation of features and problems associated with construction, maintenance, and repair of these structures is discussed.

Hirsch, Carl M. "Durability of Polymer-Coated Corrugated Steel Pipe." TRR 1001, TRB, Washington, D.C., 1984, p. 9.

Paper provides an overview of corrosion resistance and examines the recent development of polymer coated corrugated steel pipe.

Hixon, C. Dwight. "Corrugated Steel Pipe, Cross Drain Culvert Repairs for Projects: F116(6), F116(7), S-717(1)5; Le Flore County." internal Oklahoma DOT memo dated October 12, 1984.

Memo describes repair projects in the mountainous areas of eastern Oklahoma where conditions were difficult due to abrasion and erosion. Polyethylene (PE) plastic pipe with a cement grout backfill was selected for use. Conditions, materials including grout mix, and procedures are described.

Hurd, John Owen. "Field Performance of Concrete and Corrugated Steel Pipe Culverts and Bituminous Protection of Corrugated Steel Pipe Culverts." TRR 1001, TRB, Washington, D.C., 1984, p. 40.

Information is provided regarding the durability of concrete pipe, galvanized corrugated steel pipe (6 x 2-in. and 2.67 x 0.5-in. corrugations), and bituminous protection (AASHTO M 190, Types A, B, and C) of corrugated steel pipe used for culverts in Ohio.

Hurd, John Owen. "Field Performance of Concrete Pipe Culverts at Acidic Flow Sites in Ohio." TRR 1008, TRB, Washington, D.C., 1985, p. 195.

Construction and field evaluation is presented of the precast concrete arch structures (BEBO of America) that have been constructed in Minnesota since 1980.

Hurd, John O. "Field Performance of Corrugated Polyethylene Pipe Culverts in Ohio." TRR 1087, TRB, Washington, D.C., 1986, p. 1.

Total of 172 corrugated polyethylene pipe culverts 12 through 24 inches in diameter and ranging in age from 0 to 4 years were inspected in Ohio in the summer of 1985. Data pertinent to structural performance and durability of the culverts were collected at each site. No culvert showed any signs of wear even at sites with abrasive flow. The incidence of large maximum deflections or wall flattening and buckling, or both, was significantly greater for 12- and 15-in. pipes than for 18- and 24-in. pipes.

Hurd, John Owen. "Field Performance of Protective Linings for Concrete and Corrugated Steel Pipe Culverts." TRR 1001, TRB, Washington, D.C. 1984, p. 35.

Information is provided regarding the durability of protective linings for concrete pipe and galvanized corrugated steel pipe used for culverts at corrosive and abrasive sites in Ohio. All three materials have provided satisfactory protection of base pipe material at study sites, except for polymeric coating at abrasive sites. The performance of other types of less frequently used protective linings are briefly discussed.

Ikerd, Stephen R. "Invert Replacement of Corrugated Metal Structural Plate Pipe." *TRR 1001*, TRB, Washington, D.C., 1984, p. 102.

The Alabama Highway Department chose to replace worn inverts of a large diameter corrugated metal structural plate pipe with steel armor plating. The installation of these armor-plated inverts has significantly increased the useful service life of the existing pipe for a fraction of what the actual replacement cost would have been. The paper gives sketches of contractors set-up.

"Installation or Replacement of Culverts." American Railway Bridge and Building Association, Homewood, Illinois, 1984.

A brief report of a committee of the ARBBA. This is a very general report. It mentions that open cut replacement is usually the preferred repair method due to costs. Tunneling, boring and jacking are alternatives. Threading (sliplining) is also mentioned.

Jacobs, Kenneth M. "Culvert Life Study." Technical Paper 74-1, Maine Department of Transportation, Augusta, Maine, January, 1974.

Various culvert types were sampled including reinforced concrete, bituminous coated and uncoated galvanized steel, aluminum, asbestos cement and vitrified clay. Parameters of the study were to determine culvert life expectancies in Maine and the effect of environmental conditions. Resistivity, pH of the water, and stream velocities were measured and other conditions noted.

Jacobs, Kenneth M. "Durability of Drainage Structures." *TRR 1001*, TRB, Washington, D.C., 1984, p. 14.

The study evaluated various culvert materials and coatings for durability in Maine.

Katona, Michael G. and Adel Y. Ake, "Structural Design of Buried Culverts with Slotted Joints." *Journal of Structural Engineering*, Vol. 113, No. 1, American Society of Civil Engineers, New York, N.Y., June 1987, pp. 44-60.

The results of this paper are more applicable to design of new or replacement culverts.

Kinchen, Richard W. "Evaluation of the Durability of Metal Drainage Pipe." Transportation Research Record 762, TRB, Washington, D.C., 1980, p. 25.

Preliminary results are presented of a 10-year field study undertaken in Louisiana to determine the ability of aluminum and galvanized-steel culverts to resist corrosion in moderate, acidic, and low electrical-resistivity environments. All of the test culverts appear to provide satisfactory service life in moderate environments.

Koeper, John F., Lynn E. Osborn, "Collapsing 96-inch Sewer Commands Fast Cure." Public Works, Vol. 119, No. 12, November 1988 pp. 42-44.

Article discusses collapse of a 90 year old sanitary sewer line in St. Louis. High flow rates in an 8 feet circular section and 7 feet by 9 feet egg shape section had eroded invert of the line. The invert was replaced with concrete and then an inversion liner from Insituform was placed.

Koepf, A. H. and P. H. Ryan. "Abrasion Resistance of Aluminum Culvert Based on Long-Term Field Performance." TRR 1087, TRB, Washington, D.C., 1986, p. 15.

In 1968 an initial study was reported on 229 aluminum culverts that had been exposed to abrasion for 4 to 7 years. That study proposed a form of energy level for bed load materials and rated the abrasion performance of aluminum culvert through a series of energy ratings. In 1984 and 1985 the field experience of the originally reported culvert group averaged 20 years of exposure to abrasion. This paper are presents the results of the 1984-1985 study.

Kohutek, T. L. and H. E. Ross Jr. "Safety Treatment of Roadside Culverts on Low Volume Roads." FHWATX-77-225-1, Research Report 225-1, Texas Transportation Institute, College Station, Texas, March 1978.

This report describes a model recommended by AASHTO which was used by the researchers to develop guidelines for safety treating culverts on low volume roads (ADT < 20,000). The treatments considered were extending the culvert end 30' from the traveled way, providing guardrail protection, and providing grate protection.

Lisk, Ian. "Slip-lining and Concrete Put Pipe Into Action." *Water/Engineering and Management*, Vol. 135, No. 10, October 1988, p.28.

Article describes rehabilitation of 24-inch cast iron water pipe by two methods, sliplining a section with 20-inch polyethylene pipe and cement lining a longer section. Project set up was much more difficult than would be required in culvert repairs.

Manual for Railway Engineering, Vol. 1, Roadway and Ballast. American Railway Engineering Association, Chicago, Illinois, 1979.

"Jacking Culvert Pipe Through Fills," discussion of pipe jacking. Gives general procedure, equipment, crew etc.

"Methods of Installing Culverts Inside Existing Culverts" discusses surveying existing structure and allowable reduction in size. Existing pipes and arches usually lined with structures of same shape but smaller. Arches require adequate foundations.

McClellan, Thomas J. "Fish Passage Through Highway Culverts, A Field Evaluation." U.S. DOT, FHWA Office of Engineering, 1970.

Report describes a study of 62 "in-service" culverts having provisions for anadromous and native fish in Oregon. The report contains descriptions and pictures of the culverts with comments by wildlife biologists on their fish passage effectiveness.

McCrea, Robert. "Lining Deteriorated Culvert Pipes on the Jones Valley Road." Report of District Engineer, Shasta-Trinity National Forests, undated.

This paper discusses the lining of deteriorated galvanized metal pipes in the Shasta Lake Ranger District. Pipes varied from 18 to 38 inches in diameter and were degraded by hydrogen sulfide in the water. Sliplining was used with corrugated polyethylene pipe, smooth-wall polyethylene pipe and Corban RPM. Paper describes procedure, grout, and economic analysis used.

"'Mole' Speeds Tough Culvert Cleaning Job." *Roads & Bridges*, May 1987, p. 90.

Construction firm of T. J. Hall Inc. used remote controlled equipment to water-blast away hardened sediment.

Morris, G. E. and L. Bednar. "Comprehensive Evaluation of Aluminized Steel Type 2 Pipe Field Performance." TRR 1001, TRB, Washington, D.C., 1984, p. 49.

Results of 30-year field tests in 14 states, conducted by Armco on Aluminized Steel^{TM} Type 2 and galvanized steel culvert pipe. The results for aluminized steel indicated tolerance for substantially more severe environmental conditions.

Normann, Jerome M., Robert J. Houghtalen and William J. Johnston. "Hydraulic Design of Highway Culverts." FHWA-IP-85-15, HDS No. 5, Jerome M. Normann and Associates, Norfolk, VA, September 1985.

This manual, Hydraulic Design Series No. 5, is a comprehensive culvert design publication. It contains information previously contained in Hydraulic Engineering Circular (HEC) Nos. 5, 10, and 13 with hydrologic, storage routing and special culvert design information.

Patenaude, Robert. "Bacterial Corrosion of Steel Culvert Pipe in Wisconsin." TRR 1001, TRB, Washington, D.C., 1984, p. 66.

An ongoing project to investigate culvert corrosion in Wisconsin has indicated that anaerobic sulfate-reducing bacteria were a contributing factor in the corrosion of galvanized steel culvert pipe at 31 percent of the culvert sites examined since 1972. In this paper field tests are discussed and a description of the occurrences is given.

"Pipeline Rehabilitation with Polyethylene Pipe." The Society of the Plastics Industry Inc., New York, N.Y., 1988.

This brochure is a chapter that is to be incorporated into a future PPI Handbook of Polyethylene Piping. The chapter describes design considerations (selecting liner diameter, wall thickness, analyzing flow capacity, designing accesses and contract documents) and the sliplining procedure.

Pyskadlo, Robert M, and Wallace W. Renfrew. "Overview of Polymer Coatings for Corrugated Steel Pipe in New York." TRR 1001, TRB, Washington, D.C., 1984, p. 21.

This paper discusses the use of polymer coatings on corrugated steel culverts which were first used in New York State in late 1977 and 1978 on two sections of the Genesee Expressway in Livingston County. Although the evaluation is continuing, two tentative findings are discussed: stilling basins are an effective means of preventing early loss of polymer coating, and a roller-coated pipe is performing better than a laminated pipe at an aggressive site.

"Renewing Sewers with Polyolefin Pipe." Plastic Pipe Institute, New York, N.Y., undated.

Describes general procedure for slip-lining existing sewer lines with polyolefin pipes - polyethylene and polybutylene. Gives seven step procedure as well as formulas for flow capacity.

Renfrew, Wallace W. "Durability of Asphalt Coating and Paving on Corrugated Steel Culverts in New York." TRR 1001, TRB, Washington, D.C., 1984, p. 26.

This paper reports on 294 coated pipes with paved inverts which were surveyed and measured. In New York State, paving has effectively protected round pipe for 30 years and pipe-arches for at least 20 years. Beyond 30 years, paving is ineffective in protecting any corrugated steel pipe.

Ring, George W. "Culvert Durability: Where Are We?." TRR 1001, TRB, Washington, D.C., 1984, p. 1.

Paper provides an excellent overview of the use of culverts in highway drainage and the advantages and disadvantages of different pipe types. There has been extensive use of culverts under highways for more than 75 years. During that time the states have made more than 90 culvert performance studies. Prediction of the probable service life of all types of culverts is still difficult.

"Roadway Drainage Guide for Installing Culverts to Accommodate Fish." Alaska Region Report Number 42, USDA Forest Service, September 1979.

Report discusses necessary conditions for fish passage. Slower (< 1.5 cfs) stream velocity required in culverts.

Ross, Hayes E. Jr., T. J. Hirsch, Benito Jackson Jr., and Dean Sicking. "Safety Treatment of Roadside Cross-Drainage Structures." Research Report 280-1, FHWA/TX-82/37+280-1, Texas Transportation Institute, College Station, Texas, March 1981.

The report describes research to develop traffic safe end treatments for cross-drainage structures that would not appreciably restrict water flows.

Ross, Hayes E. Jr., Dean Sicking, T. J. Hirsch, Harold D. Cooner, John F. Nixon, Samuel V. Fox, and C. P. Damon." Safety Treatment of Roadside Drainage Structures." TRR 868, TRB, Washington, D.C., 1980, p. 1.

The purpose of the research was to develop traffic-safe end treatments for cross-drainage and parallel-drainage structures that would not appreciably restrict water flow.

Ruff, James F. and Steven R. Abt. "Evaluating Scour at Culvert Outlets." TRR 785, TRB, Washington, D.C., 1980, p. 37.

This paper describes an experimental study of scour at culvert outlets in two uniform noncohesive soil materials. Empirical relationships for describing the scour-hole lengths, widths, depths, and volume of material removed were developed.

Selig, Ernest T. "Review of Specification for Corrugated Metal Conduit Installations." TRR 1008, TRB, Washington, D.C., 1985, p. 15.

This paper provides an overview of CMP specifications. The national specifications for AASHTO and the American Iron and Steel Institute for buried corrugated metal conduits for the past 15 years are reviewed.

Stavios, A. J. "Galvalume Corrugated Steel Pipe: A Performance Study." TRR 1001, TRB, Washington, D.C., 1984, p. 69.

Laboratory and field tests have been used to characterize the performance of Galvalume corrugated steel pipe. After approximately 9 years, the Galvalume inverts and intermittently wet zones inside the pipe, where service is most severe, were overall in much better condition than those of comparable galvanized pipes.

"Status Report to Selected Projects Containing Experimental Features." UKTRP-86-29, Staff of Kentucky Transportation Research Program, University of Kentucky, Lexington, Kentucky, December 1986.

This report describes projects containing experimental features or innovative concepts which were selected for long term monitoring. Projects described include: the performance of metal long-span structures, metal box culverts, and precast reinforced concrete box culverts; performance of and loads on culverts; and performance evaluation of corrugated polyethylene entrance pipe.

"Steel Drainage Pipes Get Plastic Retrofit." Roads and Bridges, May 1986, adapted from a report by Curt Hayes, Research Division, Oklahoma DOT.

Article covers material in Hixon's memo with illustrations.

Summerson, T. J.. "Corrosion Resistance of Aluminum Drainage Products: The First 25 Years." TRR 1001, TRB, Washington D.C. 1984, p. 77.

A description is provided of laboratory and field evaluation procedures used to evaluate the corrosion resistance of aluminum culverts, storm drains, structural plates, and retaining walls. Results indicate that there is a qualitative relationship between corrosion resistance of aluminum and the water and soil pH and resistivities. Good performance of unprotected aluminum pipe was observed in the pH range of 4 to 9 and minimum resistivities greater than 500 ohm-cm.

Summerson, T. J. and R. J. Hogan. "Performance of Aluminum Riveted Culvert in California - 1978 Cooperative Caltrans-Kaiser Aluminum Survey." FHWA/ZCFT. 79/39, Kaiser Aluminum and Chemical Corporation, Pleasonton California, August 1979.

This report discusses monitoring of aluminum drainage pipe installations in California. While aluminum pipe was introduced in the U.S. in 1959, Caltrans did not approve their use in installations requiring a 25 or 50 year service life within the pH and resistivity ranges proposed by Kaiser Aluminum (pH 4 to 9 and resistivity > 500 ohm-cm). The report recommends that Alclad 3004 pipe be accepted by Caltrans for use inside the recommended limits.

Swanson, H. N. and D. E. Donnelly. "Performance of Culvert Materials in Various Colorado Environments." FHWA-CO-77-7, CDO4-P&R-77-7, Colorado Division of Highways, Denver, Co, September 1977.

The report describes various soil and water environments in Colorado in which culvert pipe materials have been placed. Their performance including laboratory tests on materials is described.

Temple, William H. "Evaluation of Metal Drainage Pipe Durability After Ten Years." TRR 1087, TRB, Washington, D.C., 1986, p. 7.

This study represents an investigation of the comparative performance of coated and uncoated, corrugated, galvanized steel and aluminum drainage pipe in Louisiana. The highly corrosive environments in some areas of the state make durability requirements of metal pipe as critical as strength requirements.

Tyrpak, Kenneth A. "Pipeline Rehabilitation Improves Water Flows." Public Works, Vol. 118, No. 12, December 1987, p. 39.

Describes project in Beachwood, Ohio to rehabilitate tuberculation from iron deposits in unlined cast iron water pipes. Solution chosen was the Perkins process of cement mortar pipeline rehabilitation. Only a small number of contractors in the U.S. are equipped to employ it, including Utilicon Corp. of Cleveland.

Yedinak, Brian and Keith Highlands, "Insituform Pipe Rehabilitation." Report No. PA-85-034-84-103, Pennsylvania Department of Transportation, Harrisburg, PA, April 1986.

This report covers the construction evaluation of a pipe rehabilitation project where INSITUFORM was used. Although some minor problems occurred, the INSITUFORM pipe rehabilitation seems to have been successful.

Young, W. T. "Evaluation of Highway Culvert Coating Performance." FHWA/RO-80/059, U.S. Dept. of Transportation, Washington, D.C., June 1980.

The objective of this study was to evaluate the performance of coatings for highway culverts and to recommend methods of improving culvert service life through improved coating systems and other means. The study included a literature search and field investigations in nine states.

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