Town of Bloomfield
Public Works Department

Street and Sidewalk Standard Details, Specifications, and Information

Version 2.0
November 2024

Town of Bloomfield Public Works Department
Street and Sitework Standard Details, Specifications, and Information

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Town of Bloomfield Public Works Department
Street and Sitework Standard Details, Specifications, and Information

General Specifications and Information

1. This document may be referred to as the "Bloomfield Standard Specifications".

2. **Select abbreviations and terms**:

    a. AASHTO – American Association of State Highway and Transportation Officials.

    b. ANSI - American National Standards Institute.

    c. ASTM – American Society of Testing and Materials.

    d. Authorized Public Works personnel – Town of Bloomfield Director of Public Works, Assistant Director of Public Works, Town Engineer, Deputy Town Engineer, and Operations Manager.

    e. CTDEEP – Connecticut Department of Energy and Environmental Protection.

    f. CTDOT – Connecticut Department of Transportation.

    g. CTESG – The 2023 edition of the Connecticut Guidelines for Soil Erosion & Sediment Control, issued by the Council on Soils and Water Conservation in collaboration with the CTDEEP, (publication date of September 30, 2023,) including any amendments or supplements duly issued thereto; (may also be referred to as the E & S Guidelines).

    h. DPP – Dual wall polypropylene [pipe] meeting AASHTO M330, and equivalent for fittings.

    i. FHWA – Federal Highway Administration.

    j. Form 819 – Division II (Construction Details) and Division III (Materials Section) of the State of Connecticut Department of Transportation "Standard Specifications for Roads, Bridges, Facilities, and Incidental Construction, Form 819, 2024" together with all supplements thereto issued by CTDOT.

    k. HDPE – Dual wall high density polyethylene [pipe] meeting AASHTO M294, and equivalent for fittings.

    l. MUTCD – The most recent edition of the Manual On Uniform Traffic Control Devices (MUTCD), including any supplements thereto, as published by the Federal Highway Administration.

    m. OSHA – Occupational Safety and Health Administration.

    n. PVC – Polyvinyl chloride [pipe] meeting ASTM F949 or F1803, and equivalent for fittings.

    o. RC; RCP – Reinforced concrete [pipe] meeting ASTM C 76, Class IV or V.

    p. Rights of Way Regulations – The Town of Bloomfield Rights of Way Permit Manual together with Divisions 1 through 3 (inclusive) of Chapter 17, Article III of the Town of Bloomfield Code of Ordinances.

    q. Other abbreviations, terms, and definitions may be referenced in the Rights of Way Regulations and Form 819.

2. ***Reference Specifications*** - The following listed publications, as may be amended, are identified reference specifications, as provisions thereof may be applicable, unless, and only to the extent, specifically superseded or altered by i) this "Street and Sitework Standard Details, Specifications, and Information" document, ii) by directive of authorized Public Works personnel, or iii) by directive the Chief of Police or a uniformed Police Officer or any State of Connecticut or Federal official having jurisdiction:

   a. Rights of Way Regulations (for all work within Town rights of way or properties)

   b. Form 819

   c. MUTCD

   d. CTESG

3. Copies of the Reference Specifications, or any relevant portion thereof, or the same for any other specification, detail, or information referenced herein, may be obtained from the Town Engineering Division upon request. The Town is not responsible for the completeness of provided information where a portion of a reference document is provided.

4. ***Quality of work and activities***: All work and activities, and the results of the same, shall be in accordance with commonly accepted industry standards and practice. All such work and activities shall be in accordance with applicable provisions of this this "Street and Sitework Standard Details, Specifications, and Information" document, including the reference specifications identified above or elsewhere herein), other applicable Town and/or CTDOT standards specifications, regulations, and requirements, and/or the construction or constitution of any existing facility being affected. All of the foregoing shall include any performance standards as may be contained therein. All work and activities shall be performed and the provisions hereof applied such that the best and highest result is achieved.

5. The material for extruded curb shall be portland cement concrete or asphaltic (i.e. bituminous) concrete.

6. For new installations or where practicable, extruded curb shall be installed on the pavement binder course or milled surface.

7. All storm drain pipe joints shall meet a minimum specification of soil tight, unless otherwise specified or approved by authorized Public Works personnel.

CTDOT Standard Sheets (as of January 1, 2023) Adopted as Standard Details by Bloomfield:

Sheet No.	Title
HW-211_01	Anti-tracking Pad
HW-506 01a	Endwalls
HW-506 01b	Steel Reinforcing for Endwalls
HW-506_02	Type “D_G” & “L” Endwalls
HW-506_03	Endwalls for Pipe – Arch
HW-586_01	Catch Basin and Drop Inlets Types “C” and “C-L” Structures
HW-586_02	Catch Basin (Types “C” and “C-L”) for Double Grate Type I Structures
HW-586_03	Catch Basin (Types “C” and “C-L”) for Double Grate Type II Structures
HW-586_04	Precast Catch Basin and Round Structure
HW-586_05	Precast Catch Basin Types for Double Grate Type I
HW-586_06	Precast Catch Basin Types for Double Grate Type II
HW-586_07a	Catch Basin Type “C” and “C-L” Tops
HW-586_07b	Catch Basin Type “C” and “C-L” Double Grate Type I Tops
HW-586_07c	Catch Basin Type “C” and “C-L” Double Grate Type II Tops
HW-586_07d	Catch Basin Type “C-G” and “C-M” Barrier Curb Tops
HW-586_08	Catch Basin Frames and Grates
HW-586_09	Catch Basin Lock Down Tops
HW-586_10a	Manhole Frame and Cover
HW-586_10b	Manhole Frame and Grate
HW-586_10c	Reinforced Precast Concrete Manhole
HW-586_10d	Manhole Non-Precast Concrete Unit
HW-686_02a	Drainage Pipe Ends – Sheet 1 [Corrugated Metal Pipe]
HW-686_02b	Drainage Pipe Ends – Sheet 2 [Concrete Pipe]
HW-910_17	R-B Terminal Section
HW-910_20	MASH W-Beam Hardware
HW-910_21	Metal Beam Rail (R-B MASH) Guiderail
HW-910_22	Metal Beam Rail (MD-B MASH) Guiderail
HW-910_23	Metal Beam Rail (R-B MASH) Half & Quarter Post Spacing Guiderail
HW-910_24	Metal Beam Rail Span Section Types II and III
HW-910_25	Metal Beam Rail Transition 350 to MASH

CTDOT Standard Sheets Adopted as Standard Details by Bloomfield (cont.):

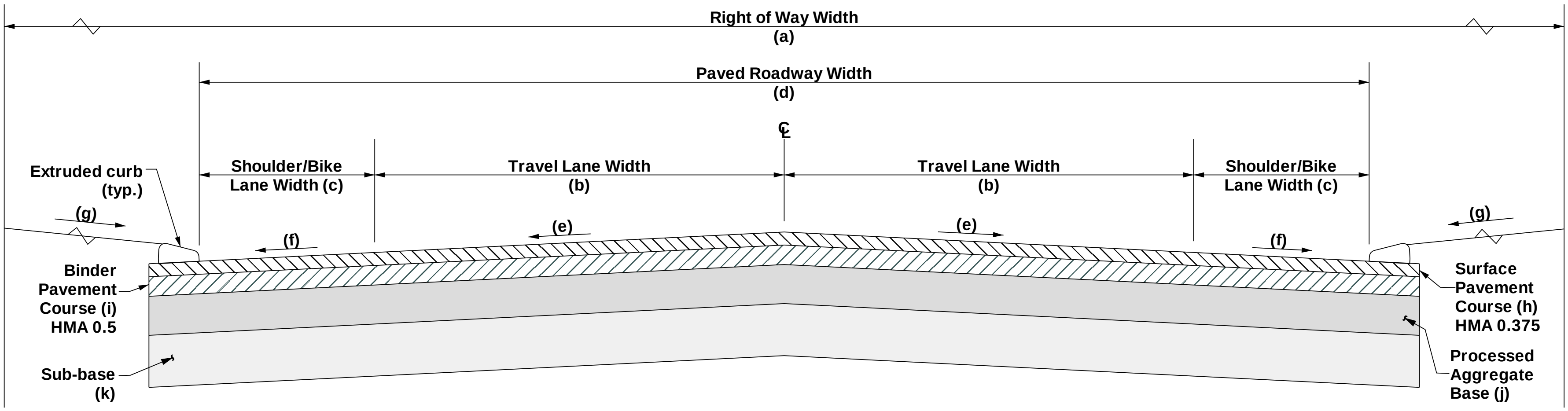
Sheet No.	Title
HW-911_01	R-B End Anchorage Type I and II
HW-911_03	Anchor In Earth Cut Slope and Anchor In Rock Cut Slope
HW-913_01a	Chain Link Fence
HW-913_01b	Chain Link Fence Hardware
HW-913_02	Chain Link Fence Gates
HW-949_01a	Landscape Planting
HW-949_01b	Tree Staking
TR-GS_01	Sign Face Sheet Aluminum R-Series Typical Sign Details
TR-GS_02	Sign Face Sheet Aluminum S&W Series Typical Sign Details
TR-GS_03	Sign Face Sheet Aluminum D,RS, E, I, & M Series Typical Sign Details
TR-1205_01	Delineation, Delineators and Object Marker Details
TR-1208_01	Sign Placement and Retroreflective Strip Details
TR-1208_02	Metal Sign Posts and Sign Mounting Details
TR-1210_04	Pavement Marking Lines and Symbols
TR-1210_08	Pavement Markings For Non Freeways
TR-1210_09	Pavement Markings For Bicycle Lanes, Parking Stalls, and Railroad Grade Crossings
TR-1220_01	Signs For Construction and Permit Operations

Note: Copies of CTDOT standard sheets may be obtained from the Town Engineering Division as needed.

CTDOT Guide Sheets Adopted as Standard Details by Bloomfield:

Sheet No.	Title
10	Sedimentation Control Systems
13	Erosion Control Measures at Catch Basins (Hay Bale, Fabric Fence, Check Dam)
16	Erosion Control Measures at Catch Basins (Fiber Roll and Silt Sack)
19	Fiber Roll Check Dam
22	Temporary Stone Check Dam
25	Permanent Stone Check Dam
64	Wing Endwall
67	Steel Reinforcing for Wing Endwall (For 12”, 15”, 18”, and 24” RCP Units)
70	Steel Reinforcing for Wing Endwall (For 30”, 36”, 42”, and 48” RCP Units)
82	Wing Endwall for Pipe Arch
85	Wing Endwall Steel Reinforcing for Pipe Arch (11x18, 13x22, 18x29, & 22x36 Size Units)
88	Wing Endwall Steel Reinforcing for Pipe Arch (27x43, 31x50, & 36x58 Size Units)
91	Precast Wing Endwall for Pipe Arch Connection Details
97	Paved Ditches and Paved Channels
106-139	Concrete Sidewalk Ramps (Index sheet plus 11 individual sheets)

Note: Copies of CTDOT guide sheets may be obtained from the Town Engineering Division as needed.



Notes:

1) See "Street Element Table" on next page for additional element dimensions/slopes/information.

2) Provided element dimensions/slopes/information are typical, and may be adjusted per approved plan or by authorized Public Works personnel as deemed appropriate thereby to accommodate particular application circumstances.

3) Other more specific details (e.g. "Street Sidewalk", "Driveway Apron", "Extruded Curb", project specific details, etc.) may supersede element information provided on this standard/typical detail.

4) 4" edge of travel lane (i.e. fog line) striping and appropriate centerline striping shall be provided where paved roadway width exceeds 28.5 feet. Such striping is optional otherwise.

5) HMA pavement shall be traffic level 2.

6) Detail vertical exaggeration is 2X.

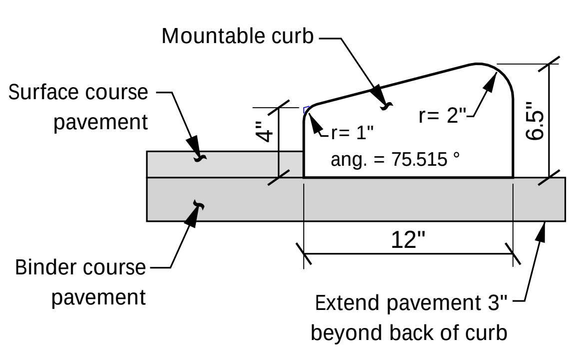
Bloomfield, CT - Standard Details

TYPICAL STREET CROSS SECTION & ELEMENTS

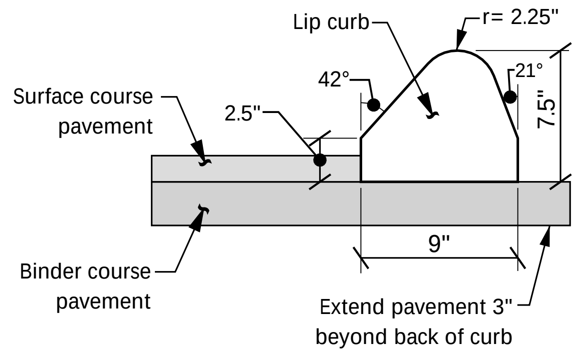
Rev: January 2024

Street Element Table

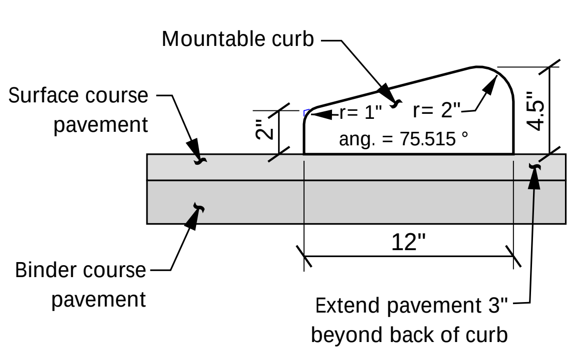
ID Desig.	Street Classification → / ↓ Parameters ↓		Local Road			Collector/Arterial Road	
			ADT < 1000 no bike lane	ADT > 1000 maybe bike lane	Industrial maybe bike lane	Minimum maybe bike lane	Standard w/ bike lane
	Speed limit		25	25	25 - 30	25 - 30	25 - 35
a	Horizontal Elements (widths in feet)	Right of way width	50	50	60	60	60
b		Travel lane width	10	10	10 - 10.5	10	10.5 - 11
c		Shoulder/bike lane width	3	4 - 5	4 - 5	4	5 - 6
d		Paved roadway width	26	28 - 30	28 - 31	28	31 - 34
e	Cross Slope Elements	Crown slope	2.5%	2.5%	2.5%	2.5%	2.0%
f		Shoulder slope	2.5%	2.5%	2.5%	2.5%	4.0%
g		Maximum slope to right of way line	16.67% (6:1)	16.67% (6:1)	16.67% (6:1)	16.67% (6:1)	16.67% (6:1)
h	Vertical Elements (thickness in inches)	Surface pavement course thickness	1.5	1.5	2	2	2
i		Binder pavement course thickness	2.5	2.5	3	3	3
j		Process aggregate base thickness	6	6	6	7	7
k		sub-base thickness	6	8	8	8	8



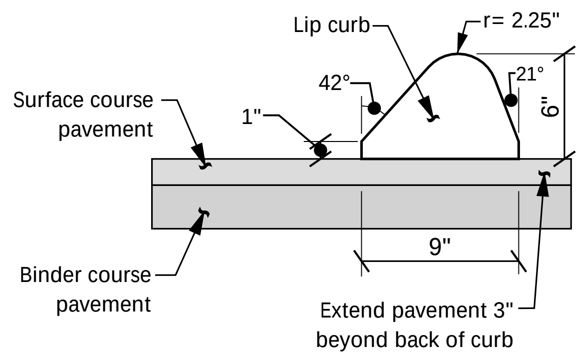
Extruded Mountable Curb
On Pavement Binder Course



Extruded Lip Curb
On Binder Course



Extruded Mountable Curb
On Pavement Surface Course

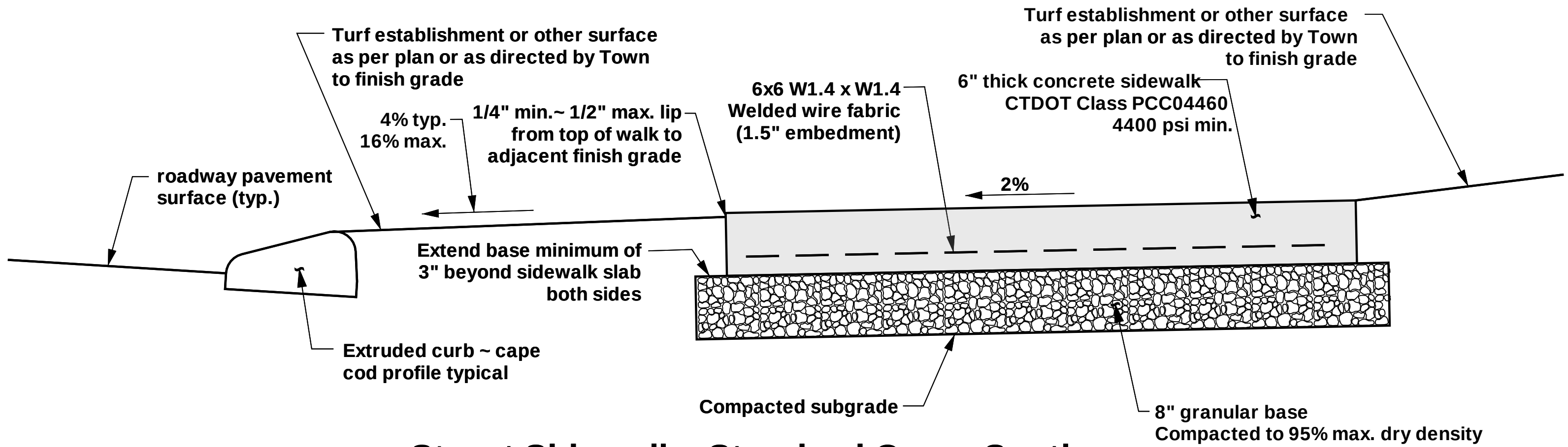


Extruded Lip Curb
On Surface Course

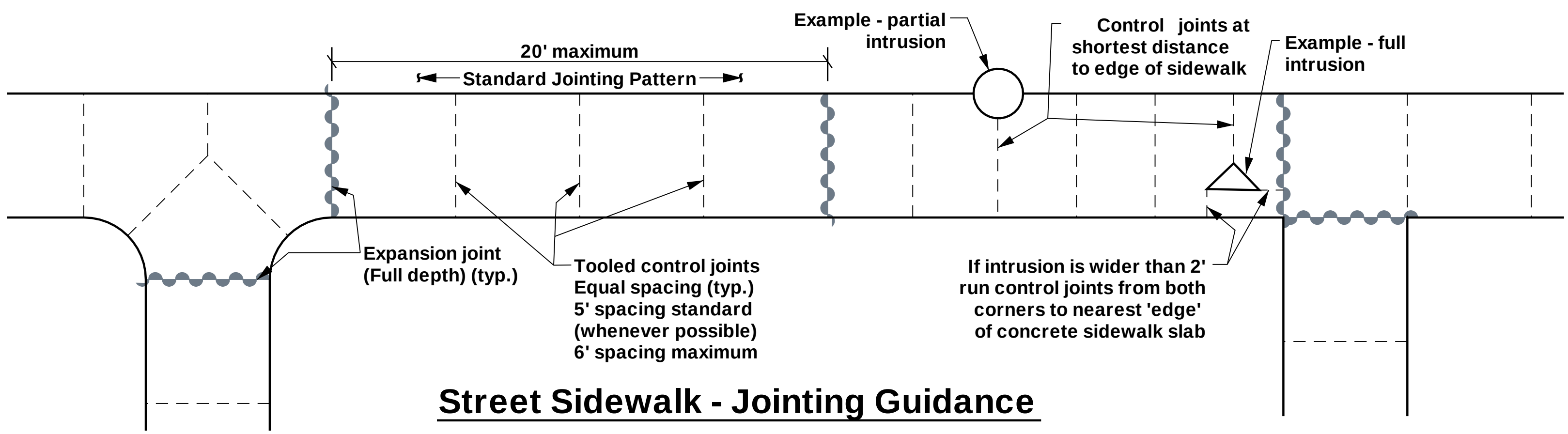
Bloomfield, CT - Standard Details

EXTRUDED CURB

Rev: January 2024



Street Sidewalk - Standard Cross Section



Street Sidewalk - Jointing Guidance

Note: This jointing guidance is typical. Where this is not practical, joints shall be installed so as to eliminate future visible cracking in the sidewalk.

Standard Notes

1) Elements and slopes may be altered at the direction/approval of Town Dept. of Public Works suthorized staff as deemed appropriate thereby.

2) Standard sidewalk width is 5 feet. Match existing width where short lengths of replacement sidewalk are being installed.

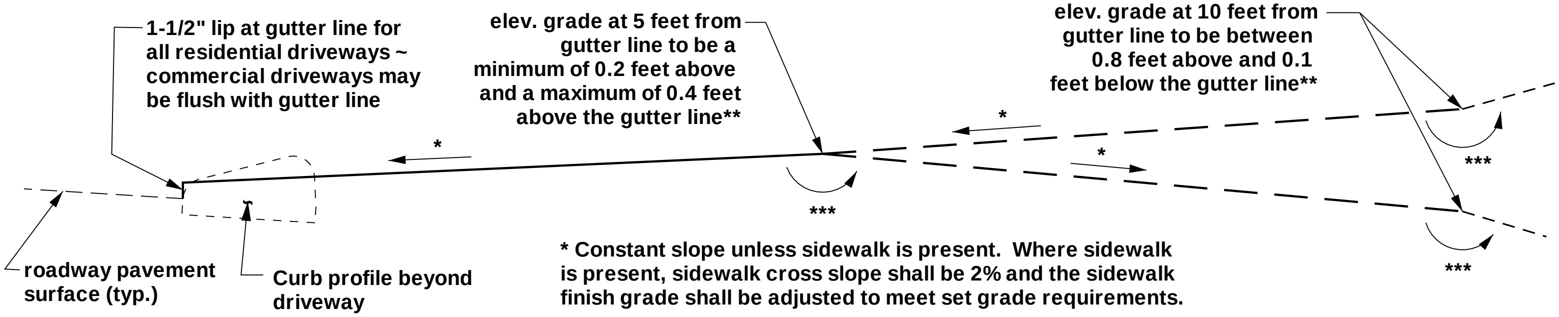
3) Horizontal distance from front face of curb (or gutter line) to front edge of walk shall be a minimum of 3 feet.

4) See driveway apron detail for maximum/ minimum grades at driveways. Adjust sidewalk grade at driveway crossings to accommodated these grade requirements.

Bloomfield, CT - Standard Details

STREET SIDEWALK

Rev: November 2024

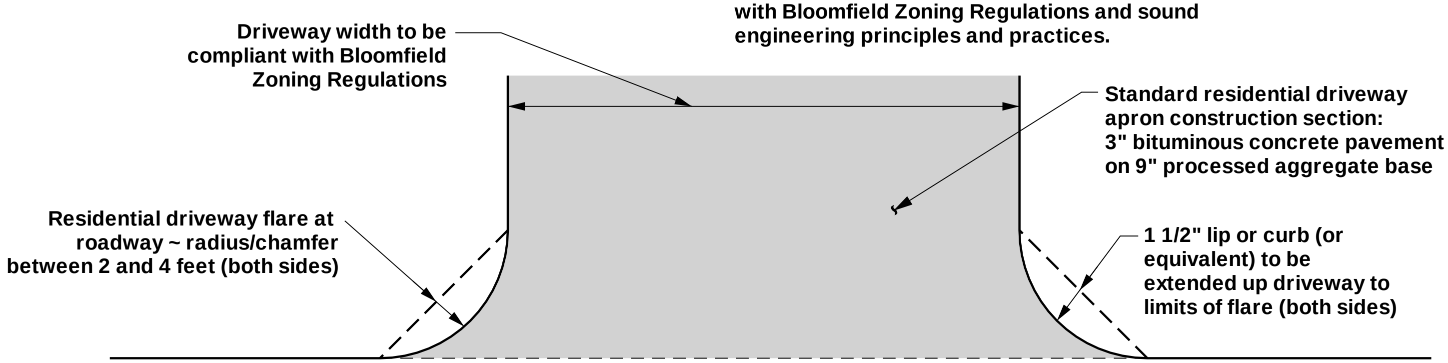


* Constant slope unless sidewalk is present. Where sidewalk is present, sidewalk cross slope shall be 2% and the sidewalk finish grade shall be adjusted to meet set grade requirements.

** Minimum and maximum grades may be adjusted by written direction/approval of the Town Engineer to accout for matching existing facilities to remain undisturbed or sidewalk locations.

*** Maximum slope change at any point is 10%

Note: Commercial driveway design to be compliant with Bloomfield Zoning Regulations and sound engineering principles and practices.



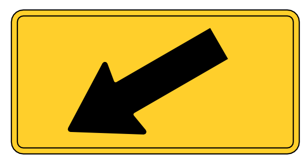
Residential Driveway Apron - Plan Detail

Bloomfield, CT - Standard Details	
	DRIVEWAY APRON Rev: January 2024

Blm-6
30" x 30"

W17-1
30" x 30"

Blm-7
24" x 18"

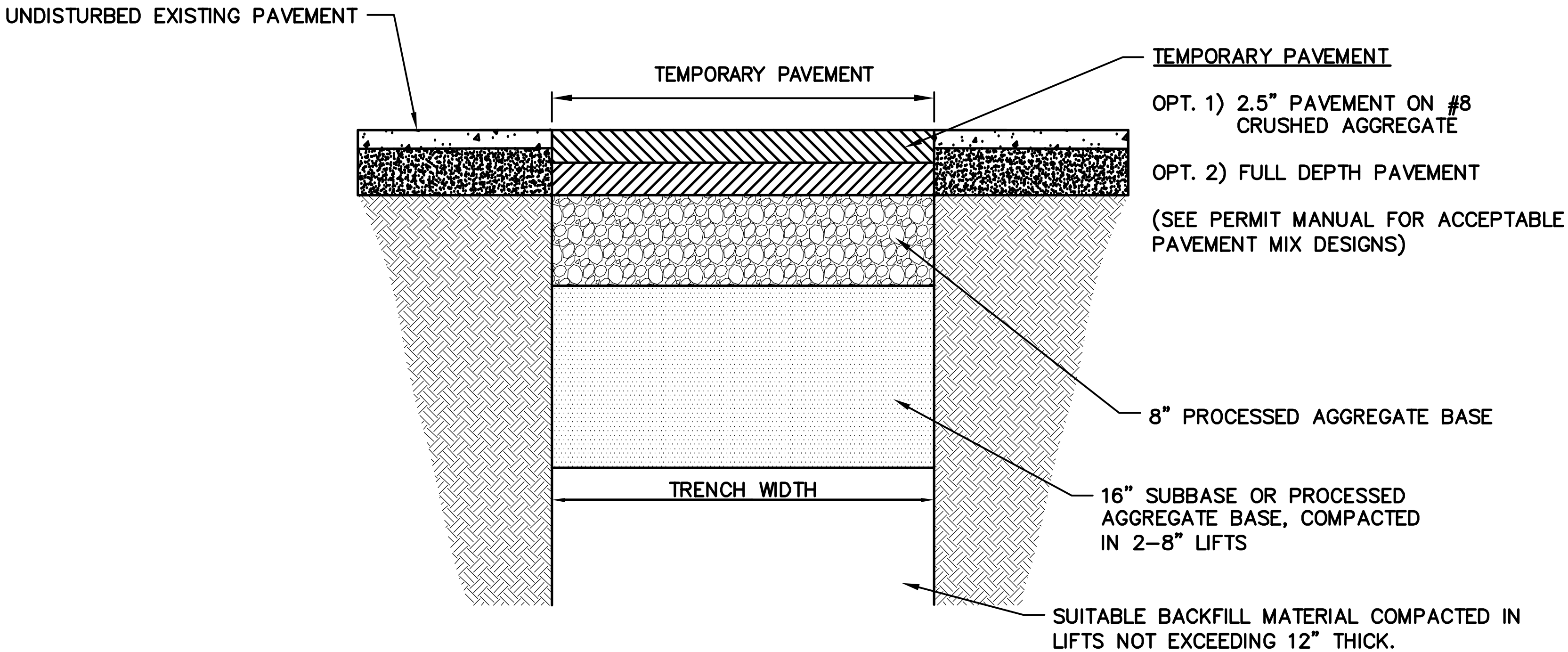


W16-7P
24" x 12"
(arrow direction
as appropriate)

Bloomfield, CT - Standard Details

SPEED HUMP SIGNS

Rev: April 2023



NOTES:

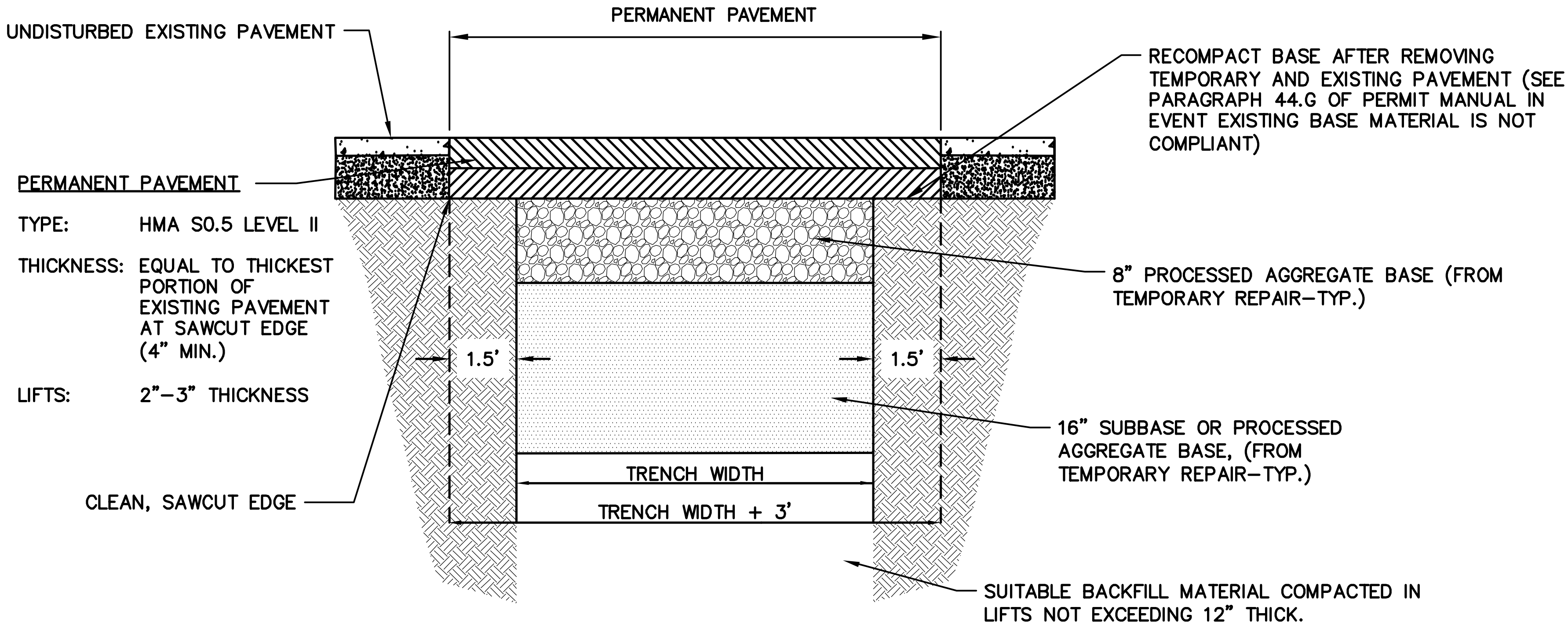
1. SEE PARAGRAPHS 40–45 OF THE BLOOMFIELD RIGHTS OF WAY PERMIT MANUAL FOR FULL REQUIREMENTS.
2. PAVEMENT MARKINGS TO BE MAINTAINED THROUGH DURATION OF CONSTRUCTION.
3. RESTORE TRAFFIC SIGNAL LOOP DETECTORS.

NOT TO SCALE

TOWN OF BLOOMFIELD, CT

TEMPORARY TRENCH REPAIR
TYPICAL CROSS-SECTION

DATE: 5/17/17



NOTES:

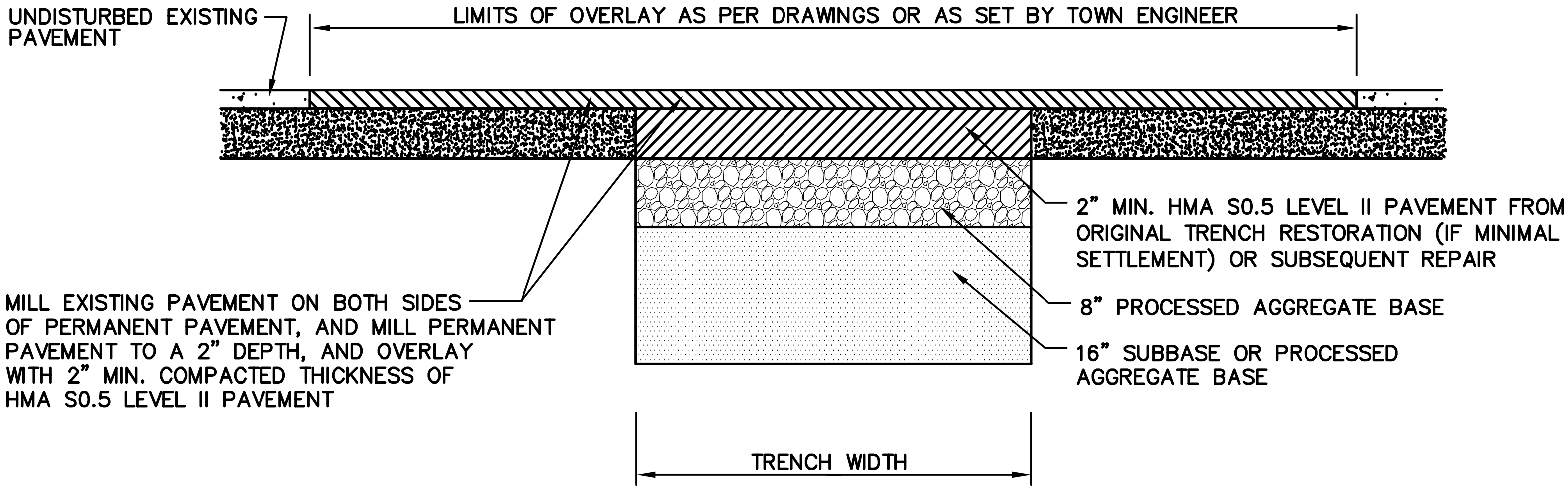
1. SEE PARAGRAPHS 40–45 OF THE BLOOMFIELD RIGHTS OF WAY PERMIT MANUAL FOR FULL REQUIREMENTS.
2. PAVEMENT MARKINGS TO BE MAINTAINED THROUGH DURATION OF CONSTRUCTION.
3. RESTORE TRAFFIC SIGNAL LOOP DETECTORS.

NOT TO SCALE

TOWN OF BLOOMFIELD, CT

PERMANENT PAVEMENT RESTORATION
TYPICAL CROSS-SECTION

DATE: 5/17/17



NOTES:

1. SEE PARAGRAPHS 40–45 OF THE BLOOMFIELD RIGHTS OF WAY PERMIT MANUAL FOR FULL REQUIREMENTS.

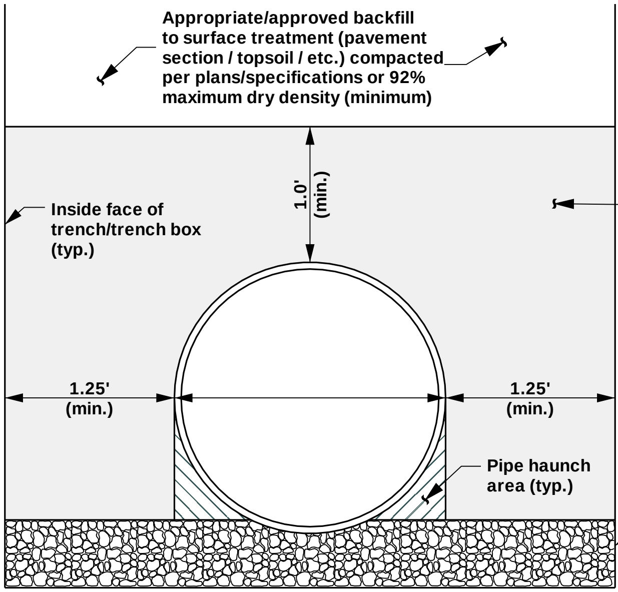
2. MINIMUM CROSS SLOPE OF 1/4 INCH PER FOOT.

NOT TO SCALE

TOWN OF BLOOMFIELD, CT

MILL & OVERLAY
TYPICAL CROSS-SECTION

DATE: 5/17/17



Underdrain Notes:

1) Underdrain pipe shall be 6" diameter perforated drain pipe unless otherwise specified.

2) Pipe shall be installed with perforations down.

3) Coarse aggregate shall be CTDOT #6 (3/4" stone) unless otherwise specified.

4) Underdrain location adjacent to edge of roadway:
- horizontal: 2.0' to 2.5' from face of curb/gutter line to center of pipe.
- vertical: top of pipe 2.5' below gutter grade.
- coarse aggregate to extend to top of pavement base course; and coarse aggregate elvelope shall abut base course and any subbase course.

Notes:

1) Pipe materials covered hereby (with standard specification reference) are: dual wall polypropylene (AASHTO M330) [DPP], dual wall high density polyethylene (AASHTO M294) [HDPE], and polyvinyl chloride (ASTM F794 or F949) [PVC] storm drain pipe.

2) Round pipe sizes covered hereby are 12" through 48" in diameter. For other sizes/shapes follow direction of plans / specifications, or manufacturer's recommendations (subject to review by the Town Engineer).

3) Minimum pipe cover from top of pipe to finish grade are as follows: 3.0 feet under a public roadway; 2.25 feet under private driveway or parking facilities; and 1.5 feet in non-vehicular traffic areas.

4) Maximum pipe cover are as follows: 12 feet for HDPE pipe; 16 feet for DPP pipe; and 25 feet for PVC pipe.

5) All pipe joints shall meet a minimum specification of soil tight, unless otherwise specified or approved by Town Engineer.

6) Appropriate excavation warning tape is to be placed between 1.0 and 1.5 feet above, and centered over, the pipe.

7) All coarse aggregate placements are to be fully wrapped in appropriate filter fabric (Mirafi 140 N or equal).

8) The initial backfill in the pipe haunch area is to be placed and compacted by hand with a shovel.

9) Where groundwater is encountered, appropriate measures shall be taken at structures or otherwise along pipe runs to properly mitigate potential negative issues due to water following the pipe bedding/envelope.

10) The contractor is responsible for complying with all applicable OSHA or other regulatory requirerments.

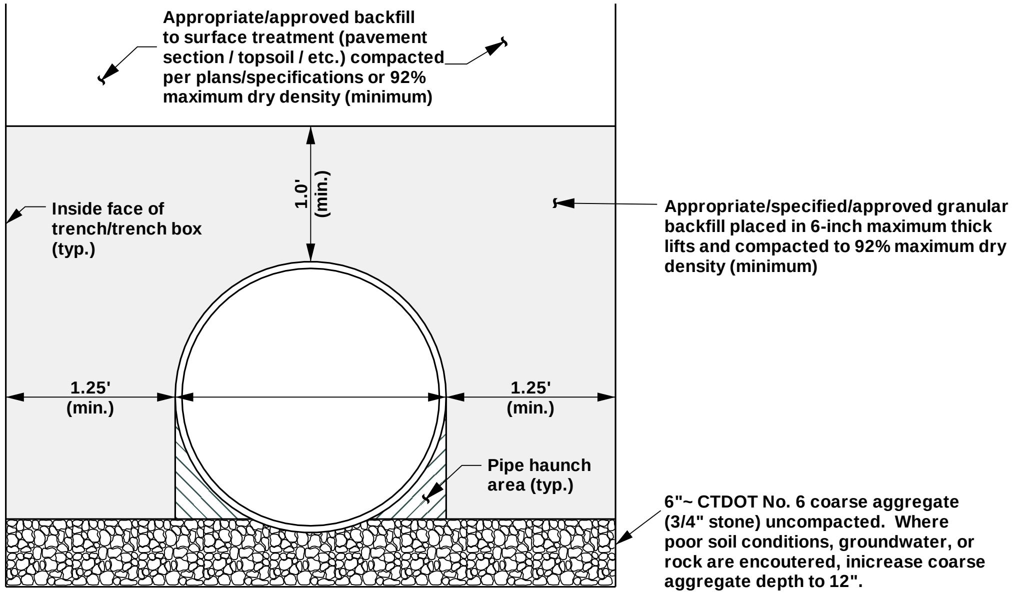
11) All Town facility pipe installations are subject to timely video inspection at the written request of authorized Public Works personnel, or per specifications. Where warranted, additional inspection/testing may be required by the same. All such inspection and testing efforts shall be at the sole expense of the installing contractor or their agent.

12) HDPE pipe is not allowed under Town roadways.

Bloomfield, CT - Standard Details

PLASTIC STORM DRAIN PIPE BEDDING & INSTALLATION

Rev: January 2024



Notes:

1) Detail covers reinforced concrete storm drain pipe [RCP] meeting specifications for ASTM C76 Class IV or V.

2) Round pipe sizes covered hereby are 12" through 60" in diameter. For other sizes/shapes follow direction of plans / specifications, or manufacturer's recommendations (subject to review by the Town Engineer).

3) Minimum pipe cover from top of pipe to finish grade are as follows: 1.5 feet under a public roadway, or private driveway or parking facilities; and 1.0 feet in non-vehicular traffic areas.

4) Maximum pipe cover shall be per manufacturer's recommendations.

5) All pipe joints shall meet a minimum specification of soil tight, unless otherwise specified or approved by Town Engineer.

6) Appropriate excavation warning tape is to be placed between 1.0 and 1.5 feet above, and centered over, the pipe.

7) All coarse aggregate placements are to be fully wrapped in appropriate filter fabric (Mirafi 140 N or equal).

8) The initial backfill in the pipe haunch area is to be placed and compacted by hand with a shovel.

9) Where groundwater is encountered, appropriate measures shall be taken at structures or otherwise along pipe runs to properly mitigate potential negative issues due to water following the pipe bedding/envelope.

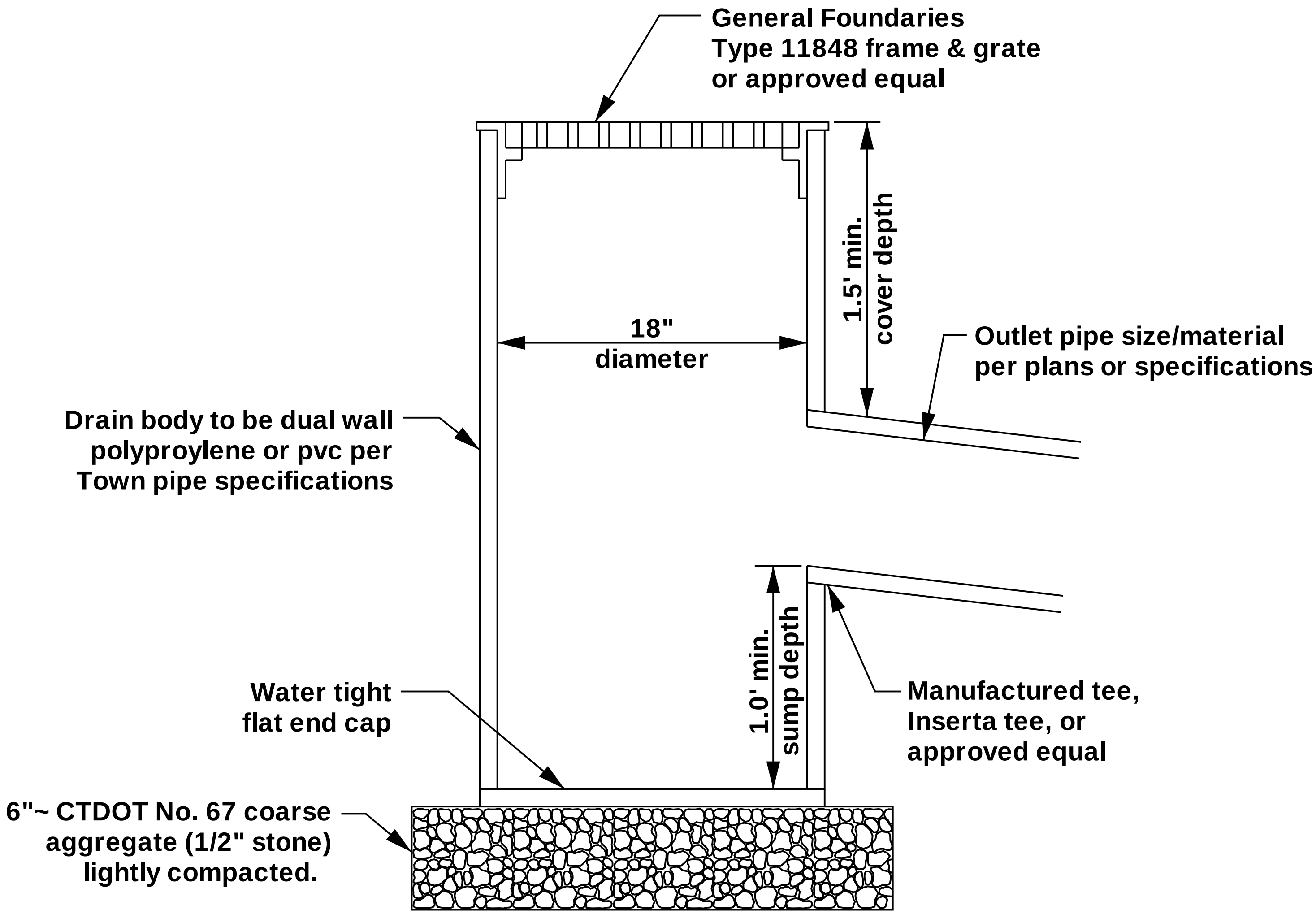
10) The contractor is responsible for complying with all applicable OSHA or other regulatory requirerments.

11) All Town facility pipe installations are subject to timely video inspection at the written request of authorized Public Works personnel, or per specifications. Where warranted, additional inspection/testing may be required by the same. All such inspection and testing efforts shall be at the sole expense of the installing contractor or their agent.

Bloomfield, CT - Standard Details

REINFORCED CONCRETE STORM DRAIN PIPE BEDDING & INSTALLATION

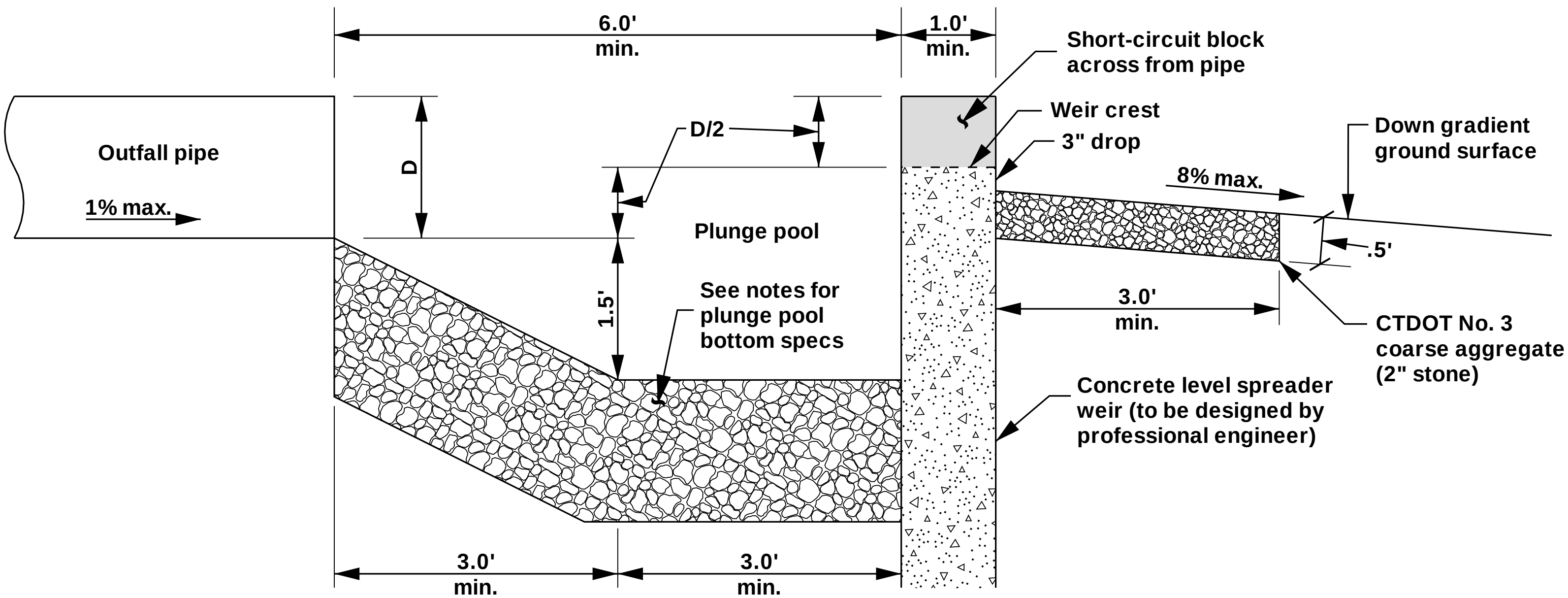
Rev: January 2024



Bloomfield, CT - Standard Details

YARD DRAIN

Rev: January 2024



Profile View

Important: See next page for level spreader notes/specifications

Bloomfield, CT - Standard Details

OUTFALL PIPE
LEVEL SPREADER
(12" - 24" Pipe Sizes)

Rev: January 2024

Outfall Pipe Level Spreader Detail
<u>Notes and Specifications</u>

1. This detail/specification is valid for outfall pipes from 12” to 24” diameter (or equivalent non-circular sizes). For other circumstances, contact the Town Engineer to discuss design.

2. The maximum design flowrate applicable to this detail/specification is 15 cfs.

3. “D” in the detail refers to the circular pipe diameter, or the pipe height for a non-circular pipe.

4. The design flowrate shall be the peak flowrate for the 25-year 24-hour storm at the outfall, unless it is determined that the peak flowrate from a shorter duration storm with a 25-year return period results in a higher flowrate; (in which case the higher flowrate should be used.)

5. The level spreader weir shall be constructed of concrete meeting CTDOT Class PCC03541 (3500 psi); and shall be designed by a professional engineer.

6. The top of the level spreader weir directly across from the pipe outlet shall be raised to diminish the possibility of short-circuiting the function of the level spreader due to the velocity and concentration of the flow exiting the pipe. This is termed the “short-circuit block”.

   a. The height of the short-circuit block shall be from the weir crest to the elevation of the crown of the pipe, i.e. the diameter/height of the pipe divided by two above the weir crest.

   b. The length of the short-circuit block along the weir structure shall be two times the diameter/width of the pipe; and shall be centered on the pipe.

7. The top elevation of the weir crest (i.e. the portion of the weir designed for the water to flow over it) shall be equal to one-half the diameter/height of the pipe above the pipe invert.

8. The minimum total length of the weir crest shall be determined as follows:

   a. Where the ground surface/vegetation down gradient is a consistent stand of well-established (or appropriately erosion protected until well-established) dense grass, or other similar vegetation, then the minimum total length of the weir crest shall be ***5 feet per 1 cfs of design flow***.

   b. Where the ground surface/vegetation down gradient is a reasonably consistent stand of well-established (or appropriately erosion protected until well-established) grass, or other similar vegetation, then the minimum total length of the weir crest shall be ***9 feet per 1 cfs of design flow***.

   c. Where the ground surface/vegetation down gradient is generally vegetated but does not meet the criteria set forth in (a.) or (b.) above (including wooded areas), then the minimum total length of the weir crest shall be ***16 feet per 1 cfs of design flow***.

   d. Level spreaders shall not be used where the ground surface down gradient is bare soil.

9. Typically, the length of the weir crest shall be split equally on either side of the short-circuit block. This may be adjusted where field circumstances make such adjustment more practical; however, in no case shall one side be longer than 60% of the total length of the weir crest.

10. The weir crest shall be level. The maximum tolerance from level shall be 0.04 feet (1/2 inch) over 8 feet.

11. Anchor walls, (essentially perpendicular extensions of the weir) shall be extended back along the plunge pool for a minimum of 2 feet at either end of the weir crest. The top of the anchor walls shall be at least as high as the crown of the outfall pipe.

12. The maximum slope of the ground surface down gradient of the weir shall be 8% for a minimum of 15 feet.

13. The initial 3 feet of ground surface down gradient of the weir shall be stabilized with a minimum of 6 inches of CTDOT No. 3 (2” stone) coarse aggregate.

14. The top of the coarse aggregate at the weir face shall be 3 inches below the weir crest.

15. The level spreader weir shall be located at least 15 feet from any down gradient property line.

16. The maximum slope of the outfall pipe shall be 1% for a minimum of 16 feet above the outfall.

17. See the detail for the dimensions associated with the plunge pool. The bottom of the plunge pool shall be level and consistent along its entire length adjacent to the weir.

18. The surface of the bottom of the plunge pool shall be stabilized with CTDOT modified riprap to a depth of at least 1.5 feet.

19. Where the level spreader is not to become the property of a public entity or is to serve more than one property, a property owner’s association shall be created to be responsible for maintenance of the level spreader.

Stormwater Outlet Protection Design

Unless otherwise approved by the Town Engineer, energy dissipation for erosion control at culvert and other storm drainage conduit outlets shall be in accordance with Chapter 10 (“Riprap Basins and Aprons”) of the most recent edition of the Federal Highway Administration Hydraulic Engineering Circular No. 14 (HEC-14), “Hydraulic Design of Energy Dissipators for Culverts and Channels”. Said Chapter 10 of the Third Edition of HEC-14 (2006) is attached hereto as part of this standard.

Riprap aprons may be used for any outlet where the circular pipe diameter (or the non-circular equivalent pipe size) is less than or equal to 60 inches, (i.e. the conduit cross-section area is less than 20 square feet), and there exists a defined channel downstream of the apron capable of carrying the entire design flow within its banks (an “adequate downstream channel”) or there exists adequate energy dissipation/erosion protection downstream of the apron (or otherwise extenuating circumstances, as determined by the Town Engineer, justify the use of a riprap apron.) For outlets not meeting these criteria, a riprap basin or special design outlet protection (subject to approval by the Town Engineer), as appropriate, shall be used (except as noted below).

The standards below apply to a single conduit outlet. Consult with the Town Engineer regarding riprap aprons design serving multiple conduits.

Equation 10.4 of HEC-14 is recommended for determining the minimum D_{50} for riprap aprons for circular culverts for tailwater depths up to the diameter of the culvert. Consult with the Town Engineer for pipe shapes other than circular.

The following values and parameters shall be used for Connecticut Department of Transportation defined riprap specifications from Form 819:

- Modified riprap: D_{50} = 5 inches; minimum apron depth = 18 inches; apron length = 4 x pipe rise.
- Intermediate riprap: D_{50} = 8 inches; minimum apron depth = 21 inches; apron length = 5 x pipe rise.
- Standard riprap: D_{50} = 15 inches; minimum apron depth = 36 inches; apron length = *.

  * Determine apron length from calculated D_{50} value applied to Table 10.1 of HEC-14.

As a general rule, modified riprap shall not be used for pipes larger than 18” diameter (or equivalent) without engineering design per Chapter 10 of HEC-14; and intermediate riprap shall not be used for pipes larger than 30” (or equivalent) without engineering design per Chapter 10 of HEC-14.

The riprap apron shall be underlain by 8” minimum of compacted granular bedding with an appropriate geotextile filter fabric between the bedding and the existing soil.

The width of the downstream riprap apron bottom at the end of the discharging conduit (including any end section) shall be a minimum of 3 times the width of the conduit, and shall be centered on the conduit.*

The bottom of the riprap apron shall (in order of preference) increase in width by .67 feet for every foot of apron length*; or, shall increase in width at a constant rate from 3 times the width of the discharging conduit to the receiving channel bottom width at the end of the apron; or, shall have a minimum width of 3 times the width of the conduit for the required length of the apron, and any transition from this width to the existing width of the channel shall be constructed of riprap with the same specifications as the apron.

The longitudinal slope of the channel within the apron length shall be less than the erosion-safe slope for the surface material/channel conditions downstream of the apron (for the design flowrate)*; or, where this requirement may not be practically met, the longitudinal slope of the channel within the apron length shall be less than the average channel slope for the initial 30 feet of the downstream channel.

Channel side slopes within the apron length shall be a maximum of 2H:1V.*

Riprap shall be extended up the channel side slopes within the apron to an elevation at least 0.5 feet above the water surface elevation for the design flow in the channel.*

*Where these criteria are met, a properly designed/constructed riprap apron may discharge into a less-than-adequate downstream channel without consulting the Town Engineer.

CHAPTER 10: RIPRAP BASINS AND APRONS

Riprap is a material that has long been used to protect against the forces of water. The material can be pit-run (as provided by the supplier) or specified (standard or special). State DOTs have standard specifications for a number of classes (sizes or gradations) of riprap. Suppliers maintain an inventory of frequently used classes. Special gradations of riprap are produced on-demand and are therefore more expensive than both pit-run and standard classes.

This chapter includes discussion of both riprap aprons and riprap basin energy dissipators. Both can be used at the outlet of a culvert or chute (channel) by themselves or at the exit of a stilling basin or other energy dissipator to protect against erosion downstream. Section 10.1 provides a design procedure for the riprap basin energy dissipator that is based on armoring a pre-formed scour hole. The riprap for this basin is a special gradation. Section 10.2 includes discussion of riprap aprons that provide a flat armored surface as the only dissipator or as additional protection at the exit of other dissipators. The riprap for these aprons is generally from State DOT standard classes. Section 10.3 provides additional discussion of riprap placement downstream of energy dissipators.

10.1 RIPRAP BASIN

The design procedure for the riprap basin is based on research conducted at Colorado State University (Simons, et al., 1970; Stevens and Simons, 1971) that was sponsored by the Wyoming Highway Department. The recommended riprap basin that is shown on Figure 10.1 and Figure 10.2 has the following features:

- The basin is pre-shaped and lined with riprap that is at least $2D_{50}$ thick.
- The riprap floor is constructed at the approximate depth of scour, h_s, that would occur in a thick pad of riprap. The h_s/D_{50} of the material should be greater than 2.
- The length of the energy dissipating pool, L_s, is $10h_s$, but no less than $3W_o$; the length of the apron, L_A, is $5h_s$, but no less than W_o. The overall length of the basin (pool plus apron), L_B, is $15h_s$, but no less than $4W_o$.
- A riprap cutoff wall or sloping apron can be constructed if downstream channel degradation is anticipated as shown in Figure 10.1.

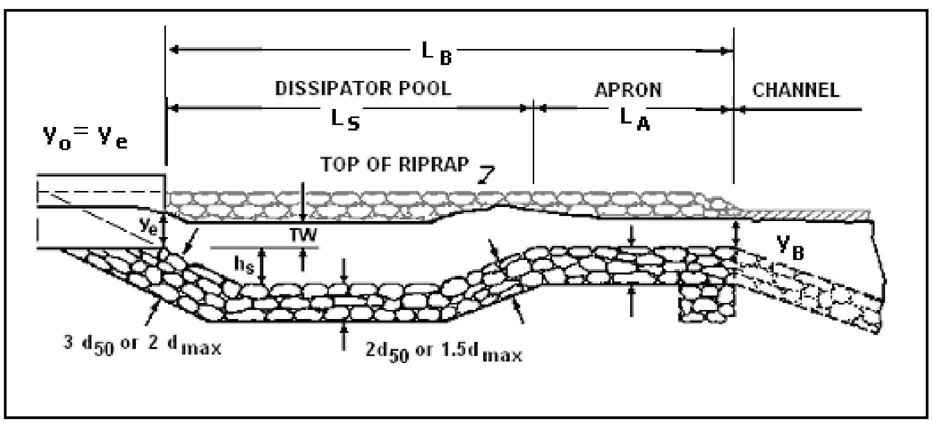


Figure 10.1. Profile of Riprap Basin

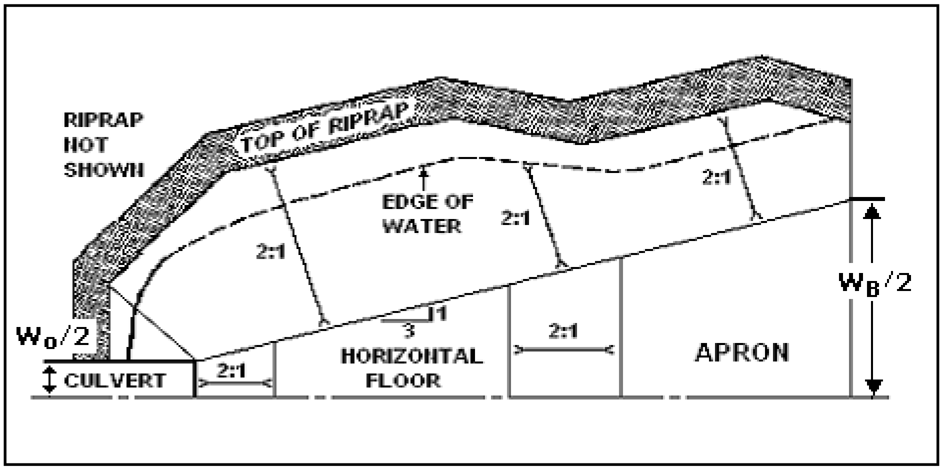


Figure 10.2. Half Plan of Riprap Basin

10.1.1 Design Development

Tests were conducted with pipes from 152 mm (6 in) to 914 mm (24 in) and 152 mm (6 in) high model box culverts from 305 mm (12 in) to 610 mm (24 in) in width. Discharges ranged from 0.003 to 2.8 m^3/s (0.1 to 100 ft^3/s). Both angular and rounded rock with an average size, D_{50}, ranging from 6 mm (1.4 in) to 177 mm (7 in) and gradation coefficients ranging from 1.05 to 2.66 were tested. Two pipe slopes were considered, 0 and 3.75%. In all, 459 model basins were studied. The following conclusions were drawn from an analysis of the experimental data and observed operating characteristics:

- The scour hole depth, h_s; length, L_s; and width, W_s, are related to the size of riprap, D_{50}; discharge, Q; brink depth, y_o; and tailwater depth, TW.
- Rounded material performs approximately the same as angular rock.
- For low tailwater ($TW/y_o < 0.75$), the scour hole functions well as an energy dissipator if $h_s/D_{50} > 2$. The flow at the culvert brink plunges into the hole, a jump forms and flow is generally well dispersed.
- For high tailwater ($TW/y_o > 0.75$), the high velocity core of water passes through the basin and diffuses downstream. As a result, the scour hole is shallower and longer.
- The mound of material that forms downstream contributes to the dissipation of energy and reduces the size of the scour hole. If the mound is removed, the scour hole enlarges somewhat.

Plots were constructed of h_s/y_e versus $V_o/(gy_e)^{1/2}$ with D_{50}/y_e as the third variable. Equivalent brink depth, y_e, is defined to permit use of the same design relationships for rectangular and circular culverts. For rectangular culverts, $y_e = y_o$ (culvert brink depth). For circular culverts, $y_e = (A/2)^{1/2}$, where A is the brink area.

Anticipating that standard or modified end sections would not likely be used when a riprap basin is located at a culvert outlet, the data with these configurations were not used to develop the design relationships. This assumption reduced the number of applicable runs to 346. A total of 128 runs had a D_{50}/y_e of less than 0.1. These data did not exhibit relationships that appeared useful for design and were eliminated. An additional 69 runs where $h_s/D_{50}<2$ were also eliminated by the authors of this edition of HEC 14. These runs were not considered reliable for design, especially those with $h_s = 0$. Therefore, the final design development used 149 runs from the study. Of these, 106 were for pipe culverts and 43 were for box culverts. Based on these data, two design relationships are presented here: an envelope design and a best fit design.

To balance the need for avoiding an underdesigned basin against the costs of oversizing a basin, an envelope design relationship in the form of Equation 10.1 and Equation 10.2 was developed. These equations provide a design envelope for the experimental data equivalent to the design figure (Figure XI-2) provided in the previous edition of HEC 14 (Corry, et al., 1983). Equations 10.1 and 10.2, however, improve the fit to the experimental data reducing the root-mean-square (RMS) error from 1.24 to 0.83.

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{g y_e}}\right) - C_o \qquad (10.1)$$

where,

h_s = dissipator pool depth, m (ft)
y_e = equivalent brink (outlet) depth, m (ft)
D_{50} = median rock size by weight, m (ft)
C_o = tailwater parameter

The tailwater parameter, C_o, is defined as:

$$\begin{aligned} C_o &= 1.4 && TW/y_e < 0.75 \\ C_o &= 4.0(TW/y_e) - 1.6 && 0.75 < TW/y_e < 1.0 \\ C_o &= 2.4 && 1.0 < TW/y_e \end{aligned} \qquad (10.2)$$

A best fit design relationship that minimizes the RMS error when applied to the experimental data was also developed. Equation 10.1 still applies, but the description of the tailwater parameter, C_o, is defined in Equation 10.3. The best fit relationship for Equations 10.1 and 10.3 exhibits a RMS error on the experimental data of 0.56.

$$\begin{aligned} C_o &= 2.0 && TW/y_e < 0.75 \\ C_o &= 4.0(TW/y_e) - 1.0 && 0.75 < TW/y_e < 1.0 \\ C_o &= 3.0 && 1.0 < TW/y_e \end{aligned} \qquad (10.3)$$

Use of the envelope design relationship (Equations 10.1 and 10.2) is recommended when the consequences of failure at or near the design flow are severe. Use of the best fit design relationship (Equations 10.1 and 10.3) is recommended when basin failure may easily be addressed as part of routine maintenance. Intermediate risk levels can be adopted by the use of intermediate values of C_o.

10.1.2 Basin Length

Frequency tables for both box culvert data and pipe culvert data of relative length of scour hole ($L_s/h_s < 6$, $6 < L_s/h_s < 7$, $7 < L_s/h_s < 8$ . . . $25 < L_s/h_s < 30$), with relative tailwater depth TW/y_e in increments of 0.03 m (0.1 ft) as a third variable, were constructed using data from 346 experimental runs. For box culvert runs L_s/h_s was less than 10 for 78% of the data and L_s/h_s was less than 15 for 98% of the data. For pipe culverts, L_s/h_s was less than 10 for 91% of the data and, L_s/h_s was less than 15 for all data. A 3:1 flare angle is recommended for the basins walls. This angle will provide a sufficiently wide energy dissipating pool for good basin operation.

10.1.3 High Tailwater

Tailwater influenced formation of the scour hole and performance of the dissipator. For tailwater depths less than 0.75 times the brink depth, scour hole dimensions were unaffected by tailwater. Above this the scour hole became longer and narrower. The tailwater parameter defined in Equations 10.2 and 10.3 captures this observation. In addition, under high tailwater conditions, it is appropriate to estimate the attenuation of the flow velocity downstream of the culvert outlet using Figure 10.3. This attenuation can be used to determine the extent of riprap protection required. HEC 11 (Brown and Clyde, 1989) or the method provided in Section 10.3 can be used for sizing riprap.

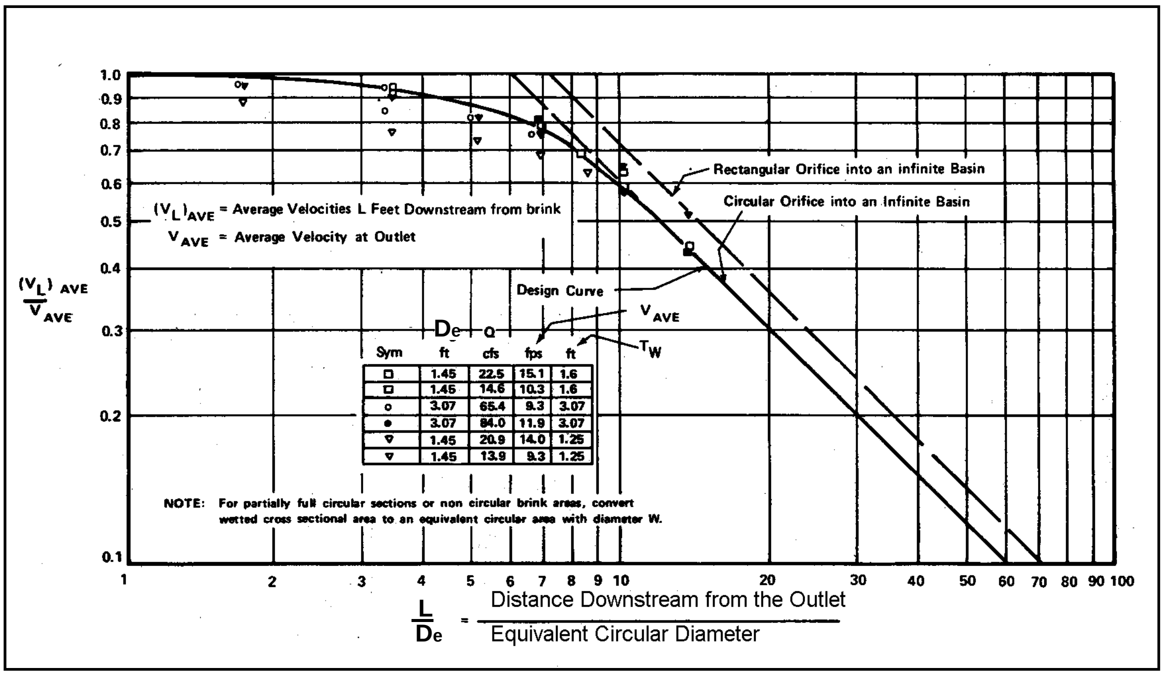


Figure 10.3. Distribution of Centerline Velocity for Flow from Submerged Outlets

10.1.4 Riprap Details

Based on experience with conventional riprap design, the recommended thickness of riprap for the floor and sides of the basin is $2D_{50}$ or $1.50D_{max}$, where D_{max} is the maximum size of rock in the riprap mixture. Thickening of the riprap layer to $3D_{50}$ or $2D_{max}$ on the foreslope of the roadway culvert outlet is warranted because of the severity of attack in the area and the necessity for preventing undermining and consequent collapse of the culvert. Figure 10.1 illustrates these riprap details. The mixture of stone used for riprap and need for a filter should meet the specifications described in HEC 11 (Brown and Clyde, 1989).

10.1.5 Design Procedure

The design procedure for a riprap basin is as follows:

Step 1. Compute the culvert outlet velocity, V_o, and depth, y_o.

For subcritical flow (culvert on mild or horizontal slope), use Figure 3.3 or Figure 3.4 to obtain y_o/D, then obtain V_o by dividing Q by the wetted area associated with y_o. D is the height of a box culvert or diameter of a circular culvert.

For supercritical flow (culvert on a steep slope), V_o will be the normal velocity obtained by using the Manning's Equation for appropriate slope, section, and discharge.

Compute the Froude number, Fr, for brink conditions using brink depth for box culverts ($y_e=y_o$) and equivalent depth ($y_e = (A/2)^{1/2}$) for non-rectangular sections.

Step 2. Select D_{50} appropriate for locally available riprap. Determine C_o from Equation 10.2 or 10.3 and obtain h_s/y_e from Equation 10.1. Check to see that $h_s/D_{50} \geq 2$ and $D_{50}/y_e \geq 0.1$. If h_s/D_{50} or D_{50}/y_e is out of this range, try a different riprap size. (Basins sized where h_s/D_{50} is greater than, but close to, 2 are often the most economical choice.)

Step 3. Determine the length of the dissipation pool (scour hole), L_s, total basin length, L_B, and basin width at the basin exit, W_B, as shown in Figures 10.1 and 10.2. The walls and apron of the basin should be warped (or transitioned) so that the cross section of the basin at the exit conforms to the cross section of the natural channel. Abrupt transition of surfaces should be avoided to minimize separation zones and resultant eddies.

Step 4. Determine the basin exit depth, $y_B = y_c$, and exit velocity, $V_B = V_c$ and compare with the allowable exit velocity, V_{allow}. The allowable exit velocity may be taken as the estimated normal velocity in the tailwater channel or a velocity specified based on stability criteria, whichever is larger. Critical depth at the basin exit may be determined iteratively using Equation 7.14:

$Q^2/g = (A_c)^3/T_c = [y_c(W_B + zy_c)]^3/ (W_B + 2zy_c)$ by trial and success to determine y_B.

$V_c = Q/A_c$

z = basin side slope, z:1 (H:V)

If $V_c \leq V_{allow}$, the basin dimensions developed in step 3 are acceptable. However, it may be possible to reduce the size of the dissipator pool and/or the apron with a larger riprap size. It may also be possible to maintain the dissipator pool, but reduce the flare on the apron to reduce the exit width to better fit the downstream channel. Steps 2 through 4 are repeated to evaluate alternative dissipator designs.

Step 5. Assess need for additional riprap downstream of the dissipator exit. If $TW/y_o \leq 0.75$, no additional riprap is needed. With high tailwater ($TW/y_o \geq 0.75$), estimate centerline velocity at a series of downstream cross sections using Figure 10.3 to determine the size and extent of additional protection. The riprap design details should be in accordance with specifications in HEC 11 (Brown and Clyde, 1989) or similar highway department specifications.

Two design examples are provided. The first features a box culvert on a steep slope while the second shows a pipe culvert on a mild slope.

Design Example: Riprap Basin (Culvert on a Steep Slope) (SI)

Determine riprap basin dimensions using the envelope design (Equations 10.1 and 10.2) for a 2440 mm by 1830 mm reinforced concrete box (RCB) culvert that is in inlet control with supercritical flow in the culvert. Allowable exit velocity from the riprap basin, V_{allow}, is 2.1 m/s. Riprap is available with a D_{50} of 0.50, 0.55, and 0.75 m. Consider two tailwater conditions: 1) TW = 0.85 m and 2) TW = 1.28 m. Given:

Q = 22.7 m^3/s

y_o = 1.22 m (normal flow depth) = brink depth

Solution

Step 1. Compute the culvert outlet velocity, V_o, depth, y_o, and Froude number for brink conditions. For supercritical flow (culvert on a steep slope), V_o will be V_n

$y_o = y_e = 1.22$ m

$V_o = Q/A = 22.7/ [1.22 (2.44)] = 7.63$ m/s

$Fr = V_o / (9.81y_e)^{1/2} = 7.63/ [9.81(1.22)]^{1/2} = 2.21$

Step 2. Select a trial D_{50} and obtain h_s/y_e from Equation 10.1. Check to see that $h_s/D_{50} \geq 2$ and $D_{50}/y_e \geq 0.1$.

Try $D_{50} = 0.55$ m; $D_{50}/y_e = 0.55/1.22 = 0.45$ (≥ 0.1 OK)

Two tailwater elevations are given; use the lowest to determine the basin size that will serve the tailwater range, that is, TW = 0.85 m.

$TW/y_e = 0.85/1.22 = 0.7$, which is less than 0.75. Therefore, from Equation 10.2, $C_o = 1.4$

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.45)^{-0.55}(2.21) - 1.4 = 1.55$$

$h_S = (h_S / y_e)y_e = 1.55 (1.22) = 1.89$ m

$h_S/D_{50} = 1.89/0.55 = 3.4$ and $h_S/D_{50} \geq 2$ is satisfied

Step 3. Size the basin as shown in Figures 10.1 and 10.2.

$L_S = 10h_S = 10(1.89) = 18.9$ m

L_S min $= 3W_o = 3(2.44) = 7.3$ m, use $L_S = 18.9$ m

$L_B = 15h_S = 15(1.89) = 28.4$ m

L_B min $= 4W_o = 4(2.44) = 9.8$ m, use $L_B = 28.4$ m

$W_B = W_o + 2(L_B/3) = 2.44 + 2(28.4/3) = 21.4$ m

Step 4. Determine the basin exit depth, $y_B = y_c$, and exit velocity, $V_B = V_c$.

$Q^2/g = (A_c)^3/T_c = [y_c(W_B + zy_c)]^3/ (W_B + 2zy_c)$

$22.7^2/9.81 = 52.5 = [y_c(21.4 + 2y_c)]^3/ (21.4 + 4y_c)$

By trial and success, $y_c = 0.48$ m, $T_c = 23.3$ m, $A_c = 10.7$ m^2

$V_B = V_c = Q/A_c = 22.7/10.7 = 2.1$ m/s (acceptable)

The initial trial of riprap (D_{50} = 0.55 m) results in a 28.4 m basin that satisfies all design requirements. Try the next larger riprap size to test if a smaller basin is feasible by repeating steps 2 through 4.

Step 2 (2nd iteration). Select riprap size and compute basin depth.

Try $D_{50} = 0.75$ m; $D_{50}/y_e = 0.75/1.22 = 0.61$ (≥ 0.1 OK)

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.61)^{-0.55}(2.21) - 1.4 = 1.09$$

$h_S = (h_S/y_e)y_e = 1.09\ (1.22) = 1.34$ m

$h_S/D_{50} = 1.34/0.75 = 1.8$ and $h_S/D_{50} \geq 2$ is not satisfied. Although not available, try a riprap size that will yield h_S/D_{50} close to, but greater than, 2. (A basin sized for smaller riprap may be lined with larger riprap.) Repeat step 2.

Step 2 (3rd iteration). Select riprap size and compute basin depth.

Try $D_{50} = 0.71$ m; $D_{50}/y_e = 0.71/1.22 = 0.58$ (≥ 0.1 OK)

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.58)^{-0.55}(2.21) - 1.4 = 1.16$$

$h_S = (h_S/y_e)y_e = 1.16\ (1.22) = 1.42$ m

$h_S/D_{50} = 1.42/0.71 = 2.0$ and $h_S/D_{50} \geq 2$ is satisfied.

Step 3 (3rd iteration). Size the basin as shown in Figures 10.1 and 10.2.

$L_S = 10h_S = 10(1.42) = 14.2$ m

L_S min $= 3W_o = 3(2.44) = 7.3$ m, use $L_S = 14.2$ m

$L_B = 15h_S = 15(1.42) = 21.3$ m

L_B min $= 4W_o = 4(2.44) = 9.8$ m, use $L_B = 21.3$ m

$W_B = W_o + 2(L_B/3) = 2.44 + 2(21.3/3) = 16.6$ m

However, since the trial D_{50} is not available, the next larger riprap size (D_{50} = 0.75 m) would be used to line a basin with the given dimensions.

Step 4 (3rd iteration). Determine the basin exit depth, $y_B = y_c$, and exit velocity, $V_B = V_c$.

$Q^2/g = (A_c)^3/T_c = [y_c(W_B + zy_c)]^3/ (W_B + 2zy_c)$

$22.7^2/9.81 = 52.5 = [y_c(16.6 + 2y_c)]^3/ (16.6 + 4y_c)$

By trial and success, $y_c = 0.56$ m, $T_c = 18.8$ m, $A_c = 9.9$ m^2

$V_B = V_c = Q/A_c = 22.7/9.9 = 2.3$ m/s (greater than 2.1 m/s; not acceptable). If the apron were extended (with a continued flare) such that the total basin length was 28.4 m, the velocity would be reduced to the allowable level.

Two feasible options have been identified. First, a 1.89 m deep, 18.9 m long pool, with a 9.5 m apron using D_{50} = 0.55 m. Second, a 1.42 m deep, 14.2 m long pool, with a 14.2 m apron using D_{50} = 0.75 m. Because the overall length is the same, the first option is likely to be more economical.

Step 5. For the design discharge, determine if $TW/y_o \le 0.75$.

For the first tailwater condition, $TW/y_o = 0.85/1.22 = 0.70$, which satisfies $TW/y_o \le 0.75$. No additional riprap needed downstream.

For the second tailwater condition, $TW/y_o = 1.28/1.22 = 1.05$, which does not satisfy $TW/y_o \le 0.75$. To determine required riprap, estimate centerline velocity at a series of downstream cross sections using Figure 10.3.

Compute equivalent circular diameter, D_e, for brink area:

$A = \pi D_e^2 /4 = (y_o)(W_o) = (1.22)(2.44) = 3.00 \text{ m}^2$

$D_e = [3.00(4)/ \pi]^{1/2} = 1.95$ m

Rock size can be determined using the procedures in Section 10.3 (Equation 10.6) or other suitable method. The computations are summarized below.

L/D_e	L (m)	V_L/V_o (Figure 10.3)	V_L (m/s)	Rock size, D_{50} (m)
10	19.5	0.59	4.50	0.43
15	29.3	0.42	3.20	0.22
20	39.0	0.30	2.29	0.11
21	41.0	0.28	2.13	0.10

The calculations above continue until $V_L \le V_{allow}$. Riprap should be at least the size shown. As a practical consideration, the channel can be lined with the same size rock used for the basin. Protection must extend at least 41.0 m downstream from the culvert brink, which is 12.6 m beyond the basin exit. Riprap should be installed in accordance with details shown in HEC 11.

<u>Design Example: Riprap Basin (Culvert on a Steep Slope) (CU)</u>

Determine riprap basin dimensions using the envelope design (Equations 10.1 and10.2) for an 8 ft by 6 ft reinforced concrete box (RCB) culvert that is in inlet control with supercritical flow in the culvert. Allowable exit velocity from the riprap basin, V_{allow}, is 7 ft/s. Riprap is available with a D_{50} of 1.67, 1.83, and 2.5 ft. Consider two tailwater conditions: 1) TW = 2.8 ft and 2) TW = 4.2 ft. Given:

Q = 800 ft^3/s

y_o = 4 ft (normal flow depth) = brink depth

Solution

Step 1. Compute the culvert outlet velocity, V_o, depth, y_o, and Froude number for brink conditions. For supercritical flow (culvert on a steep slope), V_o will be V_n.

$y_o = y_e = 4$ ft

$V_o = Q/A = 800/ [4 (8)] = 25$ ft/s

$Fr = V_o / (32.2y_e)^{1/2} = 25/ [32.2(4)]^{1/2} = 2.2$

Step 2. Select a trial D_{50} and obtain h_s/y_e from Equation 10.1. Check to see that $h_s/D_{50} \geq 2$ and $D_{50}/y_e \geq 0.1$.

Try $D_{50} = 1.83$ ft; $D_{50}/y_e = 1.83/4 = 0.46$ (≥ 0.1 OK)

Two tailwater elevations are given; use the lowest to determine the basin size that will serve the tailwater range, that is, TW = 2.8 ft.

$TW/y_e = 2.8/4 = 0.7$, which is less than 0.75. From Equation 10.2, $C_o = 1.4$

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.46)^{-0.55}(2.2) - 1.4 = 1.50$$

$h_S = (h_S /y_e)y_e = 1.50 (4) = 6.0$ ft

$h_S/D_{50} = 6.0/1.83 = 3.3$ and $h_S/D_{50} \geq 2$ is satisfied

Step 3. Size the basin as shown in Figures 10.1 and 10.2.

$L_S = 10h_S = 10(6.0) = 60$ ft

L_S min $= 3W_o = 3(8) = 24$ ft, use $L_S = 60$ ft

$L_B = 15h_S = 15(6.0) = 90$ ft

L_B min $= 4W_o = 4(8) = 32$ ft, use $L_B = 90$ ft

$W_B = W_o + 2(L_B/3) = 8 + 2(90/3) = 68$ ft

Step 4. Determine the basin exit depth, $y_B = y_c$, and exit velocity, $V_B = V_c$.

$Q^2/g = (A_c)^3/T_c = [y_c(W_B + zy_c)]^3/ (W_B + 2zy_c)$

$800^2/32.2 = 19{,}876 = [y_c(68 + 2y_c)]^3/ (68 + 4y_c)$

By trial and success, $y_c = 1.60$ ft, $T_c = 74.4$ ft, $A_c = 113.9$ ft^2

$V_B = V_c = Q/A_c = 800/113.9 = 7.0$ ft/s (acceptable)

The initial trial of riprap ($D_{50} = 1.83$ ft) results in a 90 ft basin that satisfies all design requirements. Try the next larger riprap size to test if a smaller basin is feasible by repeating steps 2 through 4.

Step 2 (2nd iteration). Select riprap size and compute basin depth.

Try $D_{50} = 2.5$ ft; $D_{50}/y_e = 2.5/4 = 0.63$ (≥ 0.1 OK)

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.63)^{-0.55}(2.2) - 1.4 = 1.04$$

$h_S = (h_S / y_e) y_e = 1.04\ (4) = 4.2$ ft

$h_S/D_{50} = 4.2/2.5 = 1.7$ and $h_S/D_{50} \geq 2$ is not satisfied. Although not available, try a riprap size that will yield h_S/D_{50} close to, but greater than, 2. (A basin sized for smaller riprap may be lined with larger riprap.) Repeat step 2.

Step 2 (3rd iteration). Select riprap size and compute basin depth.

Try $D_{50} = 2.3$ ft; $D_{50}/y_e = 2.3/4 = 0.58$ (≥ 0.1 OK)

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.58)^{-0.55}(2.2) - 1.4 = 1.15$$

$h_S = (h_S / y_e) y_e = 1.15\ (4) = 4.6$ ft

$h_S/D_{50} = 4.6/2.3 = 2.0$ and $h_S/D_{50} \geq 2$ is satisfied.

Step 3 (3rd iteration). Size the basin as shown in Figures 10.1 and 10.2.

$L_S = 10h_S = 10(4.6) = 46$ ft

L_S min $= 3W_o = 3(8) = 24$ ft, use $L_S = 46$ ft

$L_B = 15h_S = 15(4.6) = 69$ ft

L_B min $= 4W_o = 4(8) = 32$ ft, use $L_B = 69$ ft

$W_B = W_o + 2(L_B/3) = 8 + 2(69/3) = 54$ ft

However, since the trial D_{50} is not available, the next larger riprap size ($D_{50} = 2.5$ ft) would be used to line a basin with the given dimensions.

Step 4 (3rd iteration). Determine the basin exit depth, $y_B = y_c$, and exit velocity, $V_B = V_c$.

$Q^2/g = (A_c)^3/T_c = [y_c(W_B + zy_c)]^3/ (W_B + 2zy_c)$

$800^2/32.2 = 19{,}876 = [y_c(54 + 2y_c)]^3/ (54 + 4y_c)$

By trial and success, $y_c = 1.85$ ft, $T_c = 61.4$ ft, $A_c = 106.9$ ft^2

$V_B = V_c = Q/A_c = 800/106.9 = 7.5$ ft/s (not acceptable). If the apron were extended (with a continued flare) such that the total basin length was 90 ft, the velocity would be reduced to the allowable level.

Two feasible options have been identified. First, a 6-ft-deep, 60-ft-long pool, with a 30-ft-apron using $D_{50} = 1.83$ ft. Second, a 4.6-ft-deep, 46-ft-long pool, with a 44-ft-apron using $D_{50} = 2.5$ ft. Because the overall length is the same, the first option is likely to be more economical.

Step 5. For the design discharge, determine if $TW/y_o \leq 0.75$.

For the first tailwater condition, $TW/y_o = 2.8/4.0 = 0.70$, which satisfies $TW/y_o \leq 0.75$. No additional riprap needed downstream.

For the second tailwater condition, TW/y_o = 4.2/4.0 = 1.05, which does not satisfy $TW/y_o \leq 0.75$. To determine required riprap, estimate centerline velocity at a series of downstream cross sections using Figure 10.3.

Compute equivalent circular diameter, D_e, for brink area:

$A = \pi D_e^2 /4 = (y_o)(W_o) = (4)(8) = 32\ ft^2$

$D_e = [32(4)/ \pi]^{1/2} = 6.4$ ft

Rock size can be determined using the procedures in Section 10.3 (Equation 10.6) or other suitable method. The computations are summarized below.

L/D_e	L (ft)	V_L/V_o (Figure 10.3)	V_L (ft/s)	Rock size, D_{50} (ft)
10	64	0.59	14.7	1.42
15	96	0.42	10.5	0.72
20	128	0.30	7.5	0.37
21	135	0.28	7.0	0.32

The calculations above continue until $V_L \leq V_{allow}$. Riprap should be at least the size shown. As a practical consideration, the channel can be lined with the same size rock used for the basin. Protection must extend at least 135 ft downstream from the culvert brink, which is 45 ft beyond the basin exit. Riprap should be installed in accordance with details shown in HEC 11.

Design Example: Riprap Basin (Culvert on a Mild Slope) (SI)

Determine riprap basin dimensions using the envelope design (Equations 10.1 and 10.2) for a pipe culvert that is in outlet control with subcritical flow in the culvert. Allowable exit velocity from the riprap basin, V_{allow}, is 2.1 m/s. Riprap is available with a D_{50} of 0.125, 0.150, and 0.250 m. Given:

D = 1.83 m CMP with Manning's n = 0.024

S_o = 0.004 m/m

Q = 3.82 m^3/s

y_n = 1.37 m (normal flow depth in the pipe)

V_n = 1.80 m/s (normal velocity in the pipe)

TW = 0.61 m (tailwater depth)

Solution

Step 1. Compute the culvert outlet velocity, V_o, and depth, y_o.

For subcritical flow (culvert on mild slope), use Figure 3.4 to obtain y_o/D, then calculate V_o by dividing Q by the wetted area for y_o.

$K_u Q/D^{2.5} = 1.81 (3.82)/1.83^{2.5} = 1.53$

$TW/D = 0.61/1.83 = 0.33$

From Figure 3.4, $y_o/D = 0.45$

$y_o = (y_o/D)D = 0.45(1.83) = 0.823$ m (brink depth)

From Table B.2, for $y_o /D = 0.45$, the brink area ratio $A/D^2 = 0.343$

$A = (A/D^2)D^2 = 0.343(1.83)^2 = 1.15\ m^2$

$V_o = Q/A = 3.82/1.15 = 3.32$ m/s

$y_e = (A/2)^{1/2} = (1.15/2)^{1/2} = 0.76$ m

$Fr = V_o / [9.81(y_e)]^{1/2} = 3.32/ [9.81(0.76)]^{1/2} = 1.22$

Step 2. Select a trial D_{50} and obtain h_s/y_e from Equation 10.1. Check to see that $h_s/D_{50} \geq 2$ and $D_{50}/y_e \geq 0.1$.

Try $D_{50} = 0.15$ m; $D_{50}/y_e = 0.15/0.76 = 0.20$ (≥ 0.1 OK)

$TW/y_e = 0.61/0.76 = 0.80$. Therefore, from Equation 10.2,

$C_o = 4.0(TW/y_e) -1.6 = 4.0(0.80) –1.6 = 1.61$

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.20)^{-0.55}(1.22) - 1.61 = 0.933$$

$h_S = (h_S /y_e)y_e = 0.933 (0.76) = 0.71$ m

$h_S/D_{50} = 0.71/0.15 = 4.7$ and $h_S/D_{50} \geq 2$ is satisfied

Step 3. Size the basin as shown in Figures 10.1 and 10.2.

$L_S = 10h_S = 10(0.71) = 7.1$ m

L_S min $= 3W_o = 3(1.83) = 5.5$ m, use $L_S = 7.1$ m

$L_B = 15h_S = 15(0.71) = 10.7$ m

L_B min $= 4W_o = 4(1.83) = 7.3$ m, use $L_B = 10.7$ m

$W_B = W_o + 2(L_B/3) = 1.83 + 2(10.7/3) = 9.0$ m

Step 4. Determine the basin exit depth, $y_B = y_c$ and exit velocity, $V_B = V_c$.

$Q^2/g = (A_c)^3/T_c = [y_c(W_B + zy_c)]^3/ (W_B + 2zy_c)$

$3.82^2/9.81 = 1.49 = [y_c(9.0 + 2y_c)]^3/ (9.0 + 4y_c)$

By trial and success, $y_c = 0.26$ m, T_c =10.0 m, $A_c = 2.48\ m^2$

$V_c = Q/A_c = 3.82/2.48 = 1.5$ m/s (acceptable)

The initial trial of riprap ($D_{50} = 0.15$ m) results in a 10.7 m basin that satisfies all design requirements. Try the next larger riprap size to test if a smaller basin is feasible by repeating steps 2 through 4.

Step 2 (2nd iteration). Select a trial D_{50} and obtain h_s/y_e from Equation 10.1.

Try $D_{50} = 0.25$ m; $D_{50}/y_e = 0.25/0.76 = 0.33$ (≥ 0.1 OK)

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.33)^{-0.55}(1.22) - 1.61 = 0.320$$

$h_S = (h_S / y_e) y_e = 0.320 (0.76) = 0.24$ m

$h_S/D_{50} = 0.24/0.25 = 0.96$ and $h_S/D_{50} \geq 2$ is not satisfied. Although not available, try a riprap size that will yield h_S/D_{50} close to, but greater than 2. (A basin sized for smaller riprap may be lined with larger riprap.) Repeat step 2.

Step 2 (3rd iteration). Select a trial D_{50} and obtain h_s/y_e from Equation 10.1.

Try $D_{50} = 0.205$ m; $D_{50}/y_e = 0.205/0.76 = 0.27$ (≥ 0.1 OK)

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.27)^{-0.55}(1.22) - 1.61 = 0.545$$

$h_S = (h_S / y_e) y_e = 0.545 (0.76) = 0.41$ m

$h_S/D_{50} = 0.41/0.205 = 2.0$ and $h_S/D_{50} \geq 2$ is satisfied. Continue to step 3.

Step 3 (3rd iteration). Size the basin as shown in Figures 10.1 and 10.2.

$L_S = 10h_S = 10(0.41) = 4.1$ m

L_S min $= 3W_o = 3(1.83) = 5.5$ m, use $L_S = 5.5$ m

$L_B = 15h_S = 15(0.41) = 6.2$ m

L_B min $= 4W_o = 4(1.83) = 7.3$ m, use $L_B = 7.3$ m

$W_B = W_o + 2(L_B/3) = 1.83 + 2(7.3/3) = 6.7$ m

However, since the trial D_{50} is not available, the next larger riprap size ($D_{50} = 0.25$ m) would be used to line a basin with the given dimensions.

Step 4 (3rd iteration). Determine the basin exit depth, $y_B = y_c$ and exit velocity, $V_B = V_c$.

$Q^2/g = (A_c)^3/T_c = [y_c(W_B + zy_c)]^3/ (W_B + 2zy_c)$

$3.82^2/9.81 = 1.49 = [y_c(6.7 + 2y_c)]^3/ (6.7 + 4y_c)$

By trial and success, $y_c = 0.31$ m, $T_c = 7.94$ m, $A_c = 2.28$ m^2

$V_c = Q/A_c = 3.82/2.28 = 1.7$ m/s (acceptable)

Two feasible options have been identified. First, a 0.71 m deep, 7.1 m long pool, with an 3.6 m apron using $D_{50} = 0.15$ m. Second, a 0.41 m deep, 5.5 m long pool, with a 1.8 m apron using $D_{50} = 0.25$ m. The choice between these two options will likely depend on the available space and the cost of riprap.

Step 5. For the design discharge, determine if $TW/y_o \leq 0.75$

$TW/y_o = 0.61/0.823 = 0.74$, which satisfies $TW/y_o \leq 0.75$. No additional riprap needed.

Design Example: Riprap Basin (Culvert on a Mild Slope) (CU)

Determine riprap basin dimensions using the envelope design (Equations 10.1 and 10.2) for a pipe culvert that is in outlet control with subcritical flow in the culvert. Allowable exit velocity from the riprap basin, V_{allow}, is 7.0 ft/s. Riprap is available with a D_{50} of 0.42, 0.50, and 0.83 ft. Given:

D	=	6 ft CMP with Manning's n = 0.024
S_o	=	0.004 ft/ft
Q	=	135 ft^3/s
y_n	=	4.5 ft (normal flow depth in the pipe)
V_n	=	5.9 ft/s (normal velocity in the pipe)
TW	=	2.0 ft (tailwater depth)

Solution

Step 1. Compute the culvert outlet velocity, V_o, depth, y_o and Froude number.

For subcritical flow (culvert on mild slope), use Figure 3.4 to obtain y_o/D, then calculate V_o by dividing Q by the wetted area for y_o.

$K_uQ/D^{2.5} = 1.0(135)/6^{2.5} = 1.53$

$TW/D = 2.0/6 = 0.33$

From Figure 3.4, $y_o/D = 0.45$

$y_o = (y_o/D)D = 0.45(6) = 2.7$ ft (brink depth)

From Table B.2 for $y_o/D = 0.45$, the brink area ratio $A/D^2 = 0.343$

$A = (A/D^2)D^2 = 0.343(6)^2 = 12.35\ ft^2$

$V_o = Q/A = 135/12.35 = 10.9$ ft/s

$y_e = (A/2)^{1/2} = (12.35/2)^{1/2} = 2.48$ ft

$Fr = V_o / [32.2(y_e)]^{1/2} = 10.9/ [32.2(2.48)]^{1/2} = 1.22$

Step 2. Select a trial D_{50} and obtain h_s/y_e from Equation 10.1. Check to see that $h_s/D_{50} \geq 2$ and $D_{50}/y_e \geq 0.1$.

Try $D_{50} = 0.5$ ft; $D_{50}/y_e = 0.5/2.48 = 0.20$ (≥ 0.1 OK)

$TW/y_e = 2.0/2.48 = 0.806$. Therefore, from Equation 10.2,

$C_o = 4.0(TW/y_e) - 1.6 = 4.0(0.806) - 1.6 = 1.62$

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.20)^{-0.55}(1.22) - 1.62 = 0.923$$

$h_S = (h_S / y_e)y_e = 0.923\ (2.48) = 2.3$ ft

$h_S/D_{50} = 2.3/0.5 = 4.6$ and $h_S/D_{50} \geq 2$ is satisfied

Step 3. Size the basin as shown in Figures 10.1 and 10.2.

$L_S = 10h_S = 10(2.3) = 23$ ft

L_S min $= 3W_o = 3(6) = 18$ ft, use $L_S = 23$ ft

$L_B = 15h_S = 15(2.3) = 34.5$ ft

L_B min $= 4W_o = 4(6) = 24$ ft, use $L_B = 34.5$ ft

$W_B = W_o + 2(L_B/3) = 6 + 2(34.5/3) = 29$ ft

Step 4. Determine the basin exit depth, $y_B = y_c$ and exit velocity, $V_B = V_c$.

$Q^2/g = (A_c)^3/T_c = [y_c(W_B + zy_c)]^3/ (W_B + 2zy_c)$

$135^2/32.2 = 566 = [y_c(29 + 2y_c)]^3/ (29 + 4y_c)$

By trial and success, $y_c = 0.86$ ft, $T_c = 32.4$ ft, $A_c = 26.4$ ft^2

$V_c = Q/A_c = 135/26.4 = 5.1$ ft/s (acceptable)

The initial trial of riprap ($D_{50} = 0.5$ ft) results in a 34.5 ft basin that satisfies all design requirements. Try the next larger riprap size to test if a smaller basin is feasible by repeating steps 2 through 4.

Step 2 (2nd iteration). Select a trial D_{50} and obtain h_s/y_e from Equation 10.1.

Try $D_{50} = 0.83$ ft; $D_{50}/y_e = 0.83/2.48 = 0.33$ (≥ 0.1 OK)

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.33)^{-0.55}(1.22) - 1.62 = 0.311$$

$h_S = (h_S/y_e)y_e = 0.311\ (2.48) = 0.8$ ft

$h_S/D_{50} = 0.8/0.83 = 0.96$ and $h_S/D_{50} \geq 2$ is not satisfied. Although not available, try a riprap size that will yield h_S/D_{50} close to, but greater than 2. (A basin sized for smaller riprap may be lined with larger riprap.) Repeat step 2.

Step 2 (3rd iteration). Select a trial D_{50} and obtain h_s/y_e from Equation 10.1.

Try $D_{50} = 0.65$ ft; $D_{50}/y_e = 0.65/2.48 = 0.26$ (≥ 0.1 OK)

From Equation 10.1,

$$\frac{h_s}{y_e} = 0.86\left(\frac{D_{50}}{y_e}\right)^{-0.55}\left(\frac{V_o}{\sqrt{gy_e}}\right) - C_o = 0.86(0.26)^{-0.55}(1.22) - 1.62 = 0.581$$

$h_S = (h_S/y_e)y_e = 0.581\ (2.48) = 1.4$ ft

$h_S/D_{50} = 1.4/0.65 = 2.15$ and $h_S/D_{50} \geq 2$ is satisfied. Continue to step 3.

Step 3 (3rd iteration). Size the basin as shown in Figures 10.1 and 10.2.

$L_S = 10h_S = 10(1.4) = 14$ ft

L_S min $= 3W_o = 3(6) = 18$ ft, use $L_S = 18$ ft

$L_B = 15h_S = 15(1.4) = 21$ ft

L_B min = $4W_o$ = 4(6) = 24 ft, use L_B = 24 ft

$W_B = W_o + 2(L_B/3) = 6 + 2(24/3) = 22$ ft

However, since the trial D_{50} is not available, the next larger riprap size (D_{50} = 0.83 ft) would be used to line a basin with the given dimensions.

Step 4 (3rd iteration). Determine the basin exit depth, $y_B = y_c$ and exit velocity, $V_B = V_c$.

$Q^2/g = (A_c)^3/T_c = [y_c(W_B + zy_c)]^3/ (W_B + 2zy_c)$

$135^2/32.2 = 566 = [y_c(22 + 2y_c)]^3/ (22 + 4y_c)$

By trial and success, y_c = 1.02 ft, T_c =26.1 ft, A_c = 24.5 ft^2

$V_c = Q/A_c$ = 135/24.5 = 5.5 ft/s (acceptable)

Two feasible options have been identified. First, a 2.3-ft-deep, 23-ft-long pool, with an 11.5-ft-apron using D_{50} = 0.5 ft. Second, a 1.4-ft-deep, 18-ft-long pool, with a 6-ft-apron using D_{50} = 0.83 ft. The choice between these two options will likely depend on the available space and the cost of riprap.

Step 5. For the design discharge, determine if $TW/y_o \le 0.75$

TW/y_o = 2.0/2.7 = 0.74, which satisfies $TW/y_o \le 0.75$. No additional riprap needed.

10.2 RIPRAP APRON

The most commonly used device for outlet protection, primarily for culverts 1500 mm (60 in) or smaller, is a riprap apron. An example schematic of an apron taken from the Federal Lands Division of the Federal Highway Administration is shown in Figure 10.4.

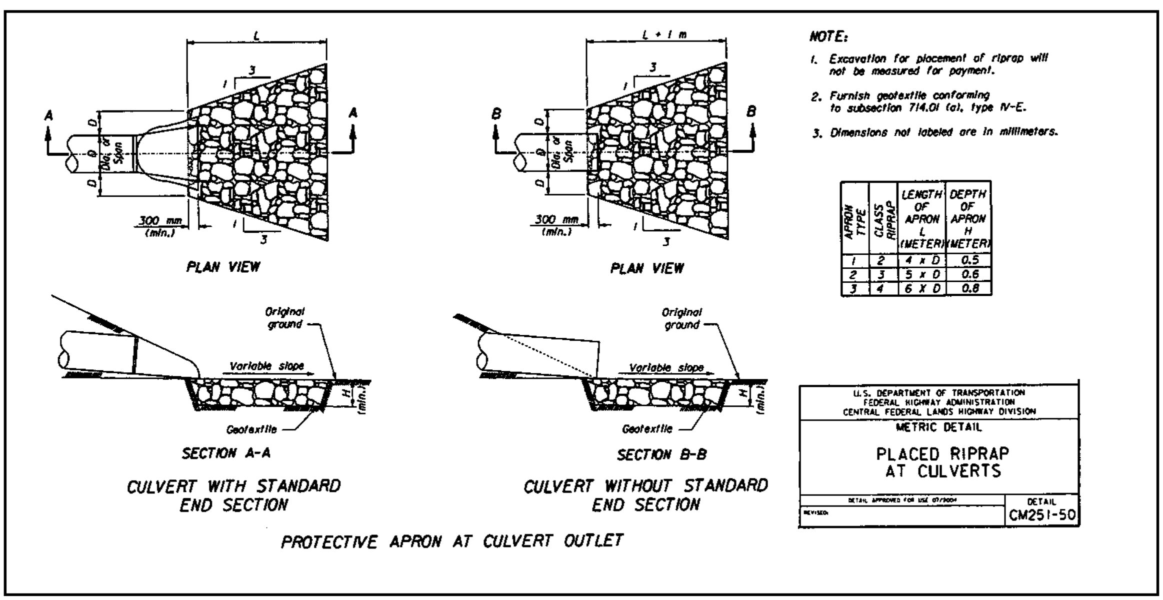


Figure 10.4. Placed Riprap at Culverts (Central Federal Lands Highway Division)

They are constructed of riprap or grouted riprap at a zero grade for a distance that is often related to the outlet pipe diameter. These aprons do not dissipate significant energy except through increased roughness for a short distance. However, they do serve to spread the flow helping to transition to the natural drainage way or to sheet flow where no natural drainage way exists. However, if they are too short, or otherwise ineffective, they simply move the location of potential erosion downstream. The key design elements of the riprap apron are the riprap size as well as the length, width, and depth of the apron.

Several relationships have been proposed for riprap sizing for culvert aprons and several of these are discussed in greater detail in Appendix D. The independent variables in these relationships include one or more of the following variables: outlet velocity, rock specific gravity, pipe dimension (e.g. diameter), outlet Froude number, and tailwater. The following equation (Fletcher and Grace, 1972) is recommended for circular culverts:

$$D_{50} = 0.2\, D \left(\frac{Q}{\sqrt{g} D^{2.5}} \right)^{4/3} \left(\frac{D}{TW} \right) \qquad (10.4)$$

where,

- D_{50} = riprap size, m (ft)
- Q = design discharge, m^3/s (ft^3/s)
- D = culvert diameter (circular), m (ft)
- TW = tailwater depth, m (ft)
- g = acceleration due to gravity, 9.81 m/s^2 (32.2 ft/s^2)

Tailwater depth for Equation 10.4 should be limited to between 0.4D and 1.0D. If tailwater is unknown, use 0.4D.

Whenever the flow is supercritical in the culvert, the culvert diameter is adjusted as follows:

$$D' = \frac{D + y_n}{2} \qquad (10.5)$$

where,

- D' = adjusted culvert rise, m (ft)
- y_n = normal (supercritical) depth in the culvert, m (ft)

Equation 10.4 assumes that the rock specific gravity is 2.65. If the actual specific gravity differs significantly from this value, the D_{50} should be adjusted inversely to specific gravity.

The designer should calculate D_{50} using Equation 10.4 and compare with available riprap classes. A project or design standard can be developed such as the example from the Federal Highway Administration Federal Lands Highway Division (FHWA, 2003) shown in Table 10.1 (first two columns). The class of riprap to be specified is that which has a D_{50} greater than or equal to the required size. For projects with several riprap aprons, it is often cost effective to use fewer riprap classes to simplify acquiring and installing the riprap at multiple locations. In such a case, the designer must evaluate the tradeoffs between over sizing riprap at some locations in order to reduce the number of classes required on a project.

Table 10.1. Example Riprap Classes and Apron Dimensions

Class	D_{50} (mm)	D_{50} (in)	Apron Length[1]	Apron Depth
1	125	5	4D	$3.5D_{50}$
2	150	6	4D	$3.3D_{50}$
3	250	10	5D	$2.4D_{50}$
4	350	14	6D	$2.2D_{50}$
5	500	20	7D	$2.0D_{50}$
6	550	22	8D	$2.0D_{50}$

[1]D is the culvert rise.

The apron dimensions must also be specified. Table 10.1 provides guidance on the apron length and depth. Apron length is given as a function of the culvert rise and the riprap size. Apron depth ranges from $3.5D_{50}$ for the smallest riprap to a limit of $2.0D_{50}$ for the larger riprap sizes. The final dimension, width, may be determined using the 1:3 flare shown in Figure 10.4 and should conform to the dimensions of the downstream channel. A filter blanket should also be provided as described in HEC 11 (Brown and Clyde, 1989).

For tailwater conditions above the acceptable range for Equation 10.4 (TW > 1.0D), Figure 10.3 should be used to determine the velocity downstream of the culvert. The guidance in Section 10.3 may be used for sizing the riprap. The apron length is determined based on the allowable velocity and the location at which it occurs based on Figure 10.3.

Over their service life, riprap aprons experience a wide variety of flow and tailwater conditions. In addition, the relations summarized in Table 10.1 do not fully account for the many variables in culvert design. To ensure continued satisfactory operation, maintenance personnel should inspect them after major flood events. If repeated severe damage occurs, the location may be a candidate for extending the apron or another type of energy dissipator.

Design Example: Riprap Apron (SI)

Design a riprap apron for the following CMP installation. Available riprap classes are provided in Table 10.1. Given:

$Q = 2.33\ m^3/s$

$D = 1.5\ m$

$TW = 0.5\ m$

Solution

Step 1. Calculate D_{50} from Equation 10.4. First verify that tailwater is within range.

TW/D = 0.5/1.5 = 0.33. This is less than 0.4D, therefore,

use TW = 0.4D = 0.4(1.5) = 0.6 m

$$D_{50} = 0.2\,D\left(\frac{Q}{\sqrt{g}D^{2.5}}\right)^{4/3}\left(\frac{D}{TW}\right) = 0.2\,(1.5)\left(\frac{2.33}{\sqrt{9.81}(1.5)^{2.5}}\right)^{4/3}\left(\frac{1.5}{0.6}\right) = 0.13\ m$$

Step 2. Determine riprap class. From Table 10.1, riprap class 2 (D_{50} = 0.15 m) is required.

Step 3. Estimate apron dimensions.

From Table 10.1 for riprap class 2,

Length, L = 4D = 4(1.5) = 6 m

Depth = $3.3D_{50}$ = 3.3 (0.15) = 0.50 m

Width (at apron end) = 3D + (2/3)L = 3(1.5) + (2/3)(6) = 8.5 m

<u>Design Example: Riprap Apron (CU)</u>

Design a riprap apron for the following CMP installation. Available riprap classes are provided in Table 10.1. Given:

Q = 85 ft^3/s
D = 5.0 ft
TW = 1.6 ft

<u>Solution</u>

Step 1. Calculate D_{50} from Equation 10.4. First verify that tailwater is within range.

TW/D = 1.6/5.0 = 0.32. This is less than 0.4D, therefore,

use TW = 0.4D = 0.4(5) = 2.0 ft

$$D_{50} = 0.2\,D\left(\frac{Q}{\sqrt{g}D^{2.5}}\right)^{4/3}\left(\frac{D}{TW}\right) = 0.2\,(5.0)\left(\frac{85}{\sqrt{32.2}(5.0)^{2.5}}\right)^{4/3}\left(\frac{5.0}{2.0}\right) = 0.43\text{ ft} = 5.2\text{ in}$$

Step 2. Determine riprap class. From Table 10.1, riprap class 2 (D_{50} = 6 in) is required.

Step 3. Estimate apron dimensions.

From Table 10.1 for riprap class 2,

Length, L = 4D = 4(5) = 20 ft

Depth = $3.3D_{50}$ = 3.3 (6) = 19.8 in = 1.65 ft

Width (at apron end) = 3D + (2/3)L = 3(5) + (2/3)(20) = 28.3 ft

10.3 RIPRAP APRONS AFTER ENERGY DISSIPATORS

Some energy dissipators provide exit conditions, velocity and depth, near critical. This flow condition rapidly adjusts to the downstream or natural channel regime; however, critical velocity may be sufficient to cause erosion problems requiring protection adjacent to the energy dissipator. Equation 10.6 provides the riprap size recommended for use downstream of energy dissipators. This relationship is from Searcy (1967) and is the same equation used in HEC 11 (Brown and Clyde, 1989) for riprap protection around bridge piers.

$$D_{50} = \frac{0.692}{S-1}\left(\frac{V^2}{2g}\right) \tag{10.6}$$

where,

D_{50} = median rock size, m (ft)

V = velocity at the exit of the dissipator, m/s (ft/s)

S = riprap specific gravity

The length of protection can be judged based on the magnitude of the exit velocity compared with the natural channel velocity. The greater this difference, the longer will be the length required for the exit flow to adjust to the natural channel condition. A filter blanket should also be provided as described in HEC 11 (Brown and Clyde, 1989).