SECTION 4

APPENDIX A
STANDARD DRAINAGE DETAILS

NOTE: Standard Drainage Details contained in Appendix A of the Storm Drainage and Erosion Control Section of this Manual have been prepared by the City of Colorado Springs and have been adopted by the Triview Metropolitan District.
**PLAN VIEW**

- **Face of Curb Expansion Joint**
- **Outlet Pipe**
- **Outlet Pipe Location Can Vary**
- **Edge of Asphalt**
- **Outlet Pipe Location Can Vary**
- **TOP OF CURB**
- **FLOW**
- **REINFORCING NOT SHOWN FOR CLARITY. SEE SHT 2 OF 3 FOR REINFORCING DETAILS.**

**SECTION A-A**

- **Opening**
- **11" x 1" Bars**
- **2" Radius**
- **4" Wide Trickle Slots**
- **4" Rad. Trickle Slots**
- **L + 4 (L: Inlet Length)**
- **4'-0"**
- **16' Min.**
- **Depth Varies from 0" at Pavement/ Apron Joint to 1/2 at Face of Curb**
- **Slope to Pipe**
- **1 1/2" / FT Max, 1/4" / FT Min.**
- **7" Conc. Gutter Connection to be Groited Using 2000 PSI Mortar**

**SECTION B-B**

- **4" Drain Hole**
- **3-5 Min.**
- **Gutter**
- **17**
- **P 3x3x1/4**

**CITY OF COLORADO SPRINGS**

**STANDARD INLET DETAIL**

**RUBBER SEALANT (FEDERAL SPECIFICATION TT-S-00227E, CLASS A, TYPE II) AND 1/2" PREMOLDED FILLER W/ REMOVABLE PLASTIC CAP**

**NOTE:**

- **PLAN VIEW**
- **SECTION A-A**
- **SECTION B-B**

**APPROVED BY:**

**REVISED 3/93 J2 **
1) All work shall be done in accordance with the standard and supplemental specifications applicable to the project.
2) Curb face assembly shall be painted yellow. One coat of shop primer and two coats of industrial enamel.
3) Steel on curb face assembly shall be ASTM A36, and shall be free of rust and dirt.
4) Reinforcing bars shall be ASTM A615, Grade 40, billet steel (deformed) and shall be marked with bar designation, grade and mill marking.
5) Inlet or outlet pipe locations may vary within the curb inlet. Reinforcing details shown are typical.
6) Curvature of lip at gutter and side openings shall be made with curved forms.
7) Depth and length of inlet may vary. Length should vary by 2' increments. Wall thickness should increase to 8" if depth is greater than 4'. For depths greater than 8', wall thickness and reinforcing shall be approved by the City Engineering Division.
8) Floor of inlet shall be trowelled to a smooth, hard surface and shall slope towards the outlet (12.5% max., 2.0% min.).
9) Storm sewer lid/frame assembly should be located as shown along back wall of curb inlet.
10) Outlet pipe to be trimmed to final shape and set in place before curb inlet is poured.
11) When curb inlet depth is greater than 4', steps are to be installed @ 15° c/c with top step located 6" below inside cover.
12) Steps shall be cast iron or extruded aluminum, 1000 lb. capacity, 12" wide with non-skid grooves and drop front on safety noses, in accordance with approved OSHA requirements.
13) Top deck slab shall have a min. 1/4" per foot slope toward the street.
14) If curb face opening is greater than 4', vertical support bars will be required at 3' intervals.
15) Top of curb to be constructed to match curb & gutter design grades at each location.
16) Minimum concrete strength = 3000 psi @ 28 days, unless otherwise approved, and shall contain ASTM C150, Type IA or IIA cement.
17) All reinforcing bars shall have a minimum 1-1/2" clear, except as noted.
18) Weld reinforcing to steel on curb face assembly, or use alternate anchor detail.
19) Pre-cast curb inlets will be accepted upon annual approval of shop drawings.
20) When pre-cast curb inlets are used, they must be bedded in a minimum 6" layer of minus 3/8" clean gravel.
NOTE: REFER TO DRAWING NO. D-10-R (SHEET 3 OF 3) FOR GENERAL CONSTRUCTION NOTES.

RADIUS POINT PERPENDICULAR TO PCR'S

VARIES DEPENDING ON OPENING NEEDED.

#4 BARS @ 9" O.C. E.W.

1/2" EXPANSION JOINT (TYP.)
USE 1/2" POLYURETHANE RUBBER SEALANT & 1/2" PREMOLDED FILLER WITH REMOVABLE PLASTIC CAP.

MANHOLE STEPS @ 16" O.C.

STANDARD REVERSIBLE FRAME & COVER WITH 5" RING.

FACE OF CURB RADIUS

PCR

3' MIN. (TYP.)

OUTLET PIPE - DIRECTION & SIZE VARIES.

GALV. STEEL RODS @ 3'-0" O.C. - SEE SECTION A-A

1 1/4" x 5" CHANNEL (PAINTED PER DRAWING NO. D-10-R & ANCHORED TO TOP SLAB)

PROJECT OF INSIDE WALL TO MATCH FACE OF CURB (TYP.)

CONSTRUCT SQUARED OFF RETURN APRON WHERE CROSS PANS ARE USED.

10' TRANSITION (TYP.)

#4 BARS @ 12" O.C.
(SEE D-10-R DETAIL)

4 BARS @ MANHOLE OPENING - 2" CL.
A 6'-0" L.
B 3'-0" L.
C 2'-0" L.

(2) #8 BARS @ 12" C/C, EXTEND OUTSIDE BAR INTO CURB HEAD (TYP.)

CITY OF COLORADO SPRINGS

STANDARD RADIAL CATCH BASIN

APPROVED BY

CITY ENGINEER

SCALE: NO SCALE
DATE: MAR. 89
DRAWN: P. R.

D-11A
SECTION A-A

CITY OF COLORADO SPRINGS
STANDARD RADIAL CATCH BASIN
APPROVED BY [Signature]

SCALE: NO SCALE
DATE: MAR 89
DRAWN: P.L.B.
SHEET: D-11 B
2 OF 2
NOTES

1. All Riprap channels to be grouted unless otherwise approved by the City Engineer.

2. Riprap shall have a specific gravity of 2.50 or 156 lbs./cu.ft.

3. Size 't' = 2.0 x (specified stone diameter).

4. z = not less than 2.5.

5. The above are minimum requirements only and are not to be considered as a substitute for a complete hydraulic design reflecting local parameters.

NOTE
ALL RIPRAPH CHANNEL DESIGN SHALL BE IN ACCORDANCE WITH THE CITY OF COLORADO SPRINGS / EL PASO COUNTY DRAINAGE CRITERIA MANUAL.
NOTES

1. NO. 40 galvanized steel screen and filter fabric to be used with weep holes >2".


3. Additional volume of coarse gravel or a complete rock underdrain system may be required if local groundwater and/or soil conditions dictate.

4. Spacing to be determined by the engineer upon final design.
**NOTES**

1. 4" Concrete Channel with 6x6, 4.4 Welded Wire Fabric (WWF). If "b" is greater than 4", floor thickness shall be minimum 6" with \#4 @ 18" E.W. This is a minimum design. Soil investigations or detailed hydraulic or structural analysis may determine that greater Concrete thickness and/or reinforcing steel is required.

2. 1/2" Contraction Joints shall be a minimum of 20' spacing unless specified otherwise by the Engineer.

3. Expansion Joints shall be a maximum of 100' spacing unless specified otherwise by the Engineer (see D-15).

4. Concrete shall be Type II, 4000 psi, with air entrainment @ 6% (+1,-2) in accordance with Sections 6.12 and 6.13.

5. The Surface shall be that of a Broom Finish.

6. z = not less than 1.0

7. L1 = 3'-6" and L2 = 6'-0" min. if Design Flow is Supercritical.

8. L1 = 2'-6" and L2 = 4'-0" min. if Design Flow is Subcritical.

9. See D-13 Weep Hole Detail.

10. Cut-off Wall spacing to be Max 200 - 250 feet, typ.
NOTES

1. Size and Spacing of Dowels to be determined by the detail design.

2. Individual requirements may demand greater dowel lengths.

3. Minimum T = 6"; Transition will be required if Channel Floor is less than 6".
NOTE:

FOR ALL INLETS ON A CONTINUOUS GRADE, THE UPSTREAM TRANSITION GUTTER LENGTH SHALL BE 10 FEET.

FOR ALL OTHER LOCATIONS, TRANSITION LENGTHS SHALL BE 3 FEET MINIMUM. ADDITIONAL 10 FEET TRANSITION NEEDED IF NORMAL RAMP CURB & GUTTER.

SECTION A-A REGULAR INLET

SECTION B-B TYPICAL END VIEW

SPECIAL DESIGN INLET

CITY OF COLORADO SPRINGS, COLORADO
COLORADO DEPARTMENT OF HIGHWAYS
CURB INLET TYPE R (MODIFIED)
APPROVED BY: Gary R. Haynes
CITY ENGINEER

SCALE AS SHOWN DATE OWN. BY
REV 1/88 JLO N-19
1 OF 2

NOTE: MANHOLE RING & COVER, SEAT & FRAME ARE TO BE LOCATED AT THE SAME END OF THE INLET.

SECTION A-A INLET WITH DROP BOX - H>5

SECTION C-C & D-D

NOTE: IS A SPECIAL DESIGN INLET TO BE USED ONLY WITH PRIOR APPROVAL BY THE CITY ENGINEER.

REvised JAN'89 PLB SPECIAL DESIGN INLET
TABLE ONE - BAR LIST FOR CURB INLETS, TYPE R

<table>
<thead>
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<th>MARK</th>
<th>DIA.</th>
<th>END TYPE</th>
<th>ALL INLETS</th>
<th>INLETS, H ≤ 5'</th>
<th>INLETS, H &gt; 5'</th>
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Note: Refer to Table Two for bars and quantities variable with height.

TABLE TWO - BARS AND QUANTITIES VARIABLE WITH H

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Additional information:

- SPECIAL DESIGN INLET
- CITY OF COLORADO SPRINGS, COLORADO
- APPROVED BY: Gary R. Hayler
- CITY ENGINEER
- SCALE: AS SHOWN
- DATE: SEPT. 87
- DWN. BY: JDO
- D-19
- SH. 2 OF 2
- REVISED JAN. 89
NOTES

1. Type I manhole shall be used in all cases unless otherwise approved by the City Engineer.

2. View and Details shown are typical for straight through design only. Design Engineer shall determine manhole base configuration and dimensions for particular pipe sizes and alignment.

3. Either ladder or steps shall be installed when manhole depth exceeds 30". Lowest step shall be a maximum of 16" above the floor.

4. Floor of the manhole shall be trowelled to a smooth, hard surface and shall slope towards the outlet (8:1 max. 1/2" per ft. min.). Floor shall be shaped and channelled; see sheet 2 for typical channel details.
1. Type II manholes shall be used only with approval of the City Engineer and only when the pipe sizes are 30" or less inside diameter.

2. View and Details are typical. Design Engineer shall determine manhole base configuration and dimensions for particular pipe sizes and alignment.

3. Either ladder or steps shall be installed when manhole depth exceeds 30". Steps in base shall be installed in "toe pockets" (see detail this sheet). Lowest step shall be a maximum of 16" above the floor.

4. Pipes shall be trimmed to final shape and set before manhole is poured.

5. Bench shall be sloped toward center of manhole base (4:1 max., 1/2" per ft. min.).

6. Floor of manhole shall be trowelled to a smooth, hard surface and shall slope towards the outlet (8:1 max., 1/2" per ft. min.). Floor shall be shaped and channelled; see details this sheet.

CITY OF COLORADO SPRINGS

STORM SEWER MANHOLE-TYPE II

APPROVED BY:

CITY ENGINEER
NOTES:

1. Type III manholes shall be used only with approval by the City Engineer and only when all of the following conditions are met:
   a. Pipe is 48" or larger inside diameter
   b. No change in pipe size
   c. No change in pipe material
   d. No change in horizontal alignment
   e. Slope is flat and continuous

2. Type III manholes shall be fabricated by the manufacturer/supplier and delivered to the site as a single unit. Field fabrication shall not be permitted.

3. Either ladder or steps shall be installed. Laid step shall be a maximum of 30° above the invert of the pipe.

CITY OF COLORADO SPRINGS
STORM SEWER MANHOLE-TYPE III
APPROVED BY

SCALE: AS SHOWN    DATE: JAN. 89    DRAWN: PL. B    ING: 0-20 C
3 OF 4
STORM SEWER MANHOLE PRECAST RISER

SECTION VIEW
SCALE: 3/8" = 1'-0"

ECCENTRIC CONE TOP
(FOR HR > 3' ½) SCALE: 1/2" = 1'-0"

NOTES
1. All work shall be done in accordance with the standard and supplemental specifications applicable to the project.

2. Precast risers shall conform to ASTM C-478.

3. Steps shall be installed when manhole depth exceeds 30". Steps shall be cast iron or extruded aluminum, 1000 lb. capacity, 12" wide with non-skid grooves and drop front on safety noses, in accordance with approved OSHA requirements.
ANCHOR 3/8" NON-SLIP RAISED PATTERNED FLOOR PLATE TO ANGLE IRON, USING TACK WELDS @ 4' C/C STAGGERED ALONG BOTH SIDES OF PLATE.

5/16" \( \rightarrow \) 1 1/2" @ 6"  

SUPPORT BAR

5/16" \( \wedge \) 1 1/2" @ 6"

1" x 1/2" STEEL SPACE BARS, CONTINUOUS ALONG PERIMETER OF FLOOR PLATE.

DETAIL 1

PROVIDE 6" LONG NO.3 REBAR ANCHORS AT 12" C/C, WELDED TO ANGLE FRAME.

<table>
<thead>
<tr>
<th>TYPE OF WALK</th>
<th>MIN. TOTAL LENGTH (L) OF PLATE</th>
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<tr>
<td>ATTACHED</td>
<td>WALK WIDTH + 10 1/2&quot;</td>
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<tr>
<td>DETACHED OR ROADWAYS</td>
<td>VARIES, HOWEVER ENTIRE CHASE SECTION SHALL BE COVERED WITHIN PUBLIC R.O.W. (SEE NOTE 5)</td>
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<table>
<thead>
<tr>
<th>1&quot; x 3/4&quot; SUPPORT BAR REQUIREMENTS</th>
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<tbody>
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<td>FLOOR PLATE WIDTH(W)</td>
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<td>6'</td>
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NOTE: EACH END OF FLOOR PLATE SHALL BE SUPPORTED BY SUPPORT BARS, WHEN SUPPORT BARS ARE SPECIFIED CHASE OPENING (C) = W - 2 3/8".

NOTES:
1. ALL EXPOSED METAL TO BE HOT DIPPED ZINE COATED. FIELD WELDS TO BE TOUCH-UP WITH COLD ZINE COATING.
2. WHEN OTHER THAN TYPE I (8") CURB EXISTS, THE CONTRACTOR SHALL REMOVE THE EXISTING CURB TO ALLOW FOR THE REQUIRED TRANSITIONS, AS FOLLOWS: BEGINNING AT THE EDGE OF THE CHASE SECTION, THERE SHALL BE A MINIMUM OF 5 FEET OF TYPE I CURB PLUS 10 FEET OF TRANSITION TO EXISTING CURB TYPE.
3. ALL REMOVAL OF EXISTING CURB SHALL BE BY SAW-CUT, OR BY REMOVAL TO AN EXISTING EXPANSION OR COLD JOINT REMAINING SECTION AFTER SAW CUTTING TO BE MINIMUM 4' IN LENGTH.
4. CHASE SECTION TO BE Poured MONOLITHICALLY WITH CURB & GUTTER SECTION AND CUT-OFF WALL.
5. WHEN CHASE SECTION LENGTH(L) EXCEEDS 15', PROVIDE TOOL JOINT IN CONCRETE AT MAXIMUM OF 10' SPACING FABRICATE FLOOR PLATES IN MULTIPLE SECTION NOT TO EXCEED 10' IN LENGTH.

CITY OF COLORADO SPRINGS

CURB OPENING DETAIL

APPROVED BY

CITY ENGINEER

SCALE: NO SCALE   DATE: JAN. 89   DRAWN: P.L.B.   SHEET: D-21  2 OF 2
### TABLE I: 2 1/2" & 1/2" Corrugations
#### Round Steel Pipe
<table>
<thead>
<tr>
<th>PIPE SIZE</th>
<th>WALL THICKNESS</th>
<th>HEIGHT OF COVER LIMITS, ft</th>
<th>DIA.</th>
<th>WALL THICKNESS</th>
<th>HEIGHT OF COVER LIMITS, (\text{in.})</th>
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### TABLE II: 3" & 4" Corrugations
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### TABLE III: 125mm & 25mm Corrugations
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**General Notes:**

- All work shall be done in accordance with the standards specified, approved by the Engineer.
- The work shall be done in accordance with the standard specifications, approved by the Engineer.
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- The work shall be done in accordance with the standard specifications, approved by the Engineer.

**CITY OF COLORADO SPRINGS**

**METAL CULVERT PIPE**

**APPROVED BY:**

**SCALE:**

**DATE:**

**DRAWN:**

**SHEET:**
### TABLE I — 6" x 2" CORRUGATIONS ROUND STEEL PIPE

<table>
<thead>
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### TABLE II — 6" x 2" CORRUGATIONS STEEL PIPE - ARCH

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### GENERAL NOTES

All work shall be done in accordance with the standards specified and adopted by the Department of Highways, City of Colorado Springs Engineering Division, and any revisions by the City of Colorado Springs Engineering Division.

CITY OF COLORADO SPRINGS
STRUCTURAL PLATE
APPROVED BY:

SCALE: NO SCALE
DATE: JAN. 27
SHEET: 0 - 27
Adopted from and in conformance with the State of Colorado Department of Highways with Revisions by the City of Colorado Springs Engineering Division

**STANDARD M-601-10**

(JANUARY, 1932)

*Depth of toe wall to be increased if required by scour potential. Indicate dimension on plan.*

**TYPICAL BAR LAYOUT FOR CONCRETE HEADWALLS**

**HEADWALL FOR CMP - ARCH**

**HEADWALL FOR RCP - ROUND**

**HEADWALL FOR CMP - ROUND**

**HEADWALL FOR STRUCTURAL PLATE - ARCH**

**GENERAL NOTES**

All work shall be done in accordance with the Standard Specifications and/or Division of the City of Colorado Springs.

Concrete sand for Class 0 and 0.

Headwall shall be punched in the proper E wire shown on the plans.

For Wingwall details, see Standard M-601-10.

Volume of pipe has been deducted from Steel and Concrete requirements.

*Note: All dimensions shown are in inches.*
**TRENCH BEDDING CLASSIFICATION - ROUND PRECAST CONCRETE PIPE**

**CLASS A**
- Reinforced $A_e = 1.05$, $L_1 = 4.8$
- Plain $A_e = 0.44$, $L_1 = 3.8$

**CLASS B**
- $L_1 = 1.9$

**CLASS C**
- $L_1 = 1.5$

---

**Notes:**
- For Class B and C beddings, subgrades should be excavated or over-excavated, if necessary, to provide a uniform foundation free of protruding rocks.
- Special care may be necessary with Class A or other unyielding foundations to cushion pipe from shock when blasting can be anticipated in the area.

---

**Legend**
- $B_e$ = outside diameter
- $H$ = backfill cover above top of pipe
- $D$ = inside diameter
- $d$ = depth of bedding material below pipe
- $A_e$ = area of transverse steel in the cradle or arch expressed as a percentage of area of concrete or invert or crown.

---

**City of Colorado Springs**
**Trench Bedding Classification**
**Approved by: J. C. Eng."**

**Scale:** No Scale  **Date:** Jan. 90  **Drawn:** R.L.B.  **Sheet:** D-30
TRENCH BEDDING FOR FLEXIBLE PIPE

SLOPE TRENCH AS REQUIRED ABOVE TOP OF PIPE ZONE.

MIN D/8 (12" MIN.)

LEVEL LIFTS OF BEDDING BACKFILL, PLACED IN LAYERS 6" TO 12" THICK, AND THEN COMPACTED. (GRANULAR MATERIAL)

BEDDING BACKFILL COMPACTED UNDER HAUNCHES TO SPRING LINE.

FOR NARROW TRENCH, W < 24", SHAPE BEDDING TO PIPE INVERT FOR A WIDTH OF D/2.

ADDITIONAL FOUNDATION PREPARATION MAY BE REQUIRED IN UNSTABLE TRENCH CONDITIONS AS DIRECTED BY THE ENGINEER.

ORDINARY TRENCH CONDITION

GRANULAR MATERIAL 6" MIN.

WHERE UNSUITABLE MATERIAL IS ENCOUNTERED OVEREXCAVATE AND BACKFILL WITH SELECT GRANULAR MATERIAL PER SPECIFICATIONS, MINIMUM COMPACTION 90% STANDARD PROCTOR DENSITY.

MIN. D/8 (12" MIN.)

CORNER SUPPORT ZONE
EXCELLENT MATERIAL, HIGHLY COMPACTED.

SLOPE TRENCH AS REQUIRED ABOVE TOP OF PIPE ZONE. UNCLASSIFIED TRENCH BACKFILL (UNLESS CLASSIFIED MATERIAL IS SPECIFIED)

LEVEL LIFTS OF BEDDING BACKFILL, PLACED IN LAYERS 6" TO 12" THICK, AND THEN COMPACTED. (GRANULAR MATERIAL)

BEDDING BACKFILL COMPACTED UNDER HAUNCHES TO SPRING LINE.

FOR NARROW TRENCH, W < 24", SHAPE BEDDING TO PIPE INVERT FOR A WIDTH OF D/2.

ADDITIONAL FOUNDATION PREPARATION MAY BE REQUIRED IN UNSTABLE TRENCH CONDITIONS AS DIRECTED BY THE ENGINEER.

UNCLASSIFIED BACKFILL

LEVEL LIFTS OF BEDDING BACKFILL, PLACED IN LAYERS 6" TO 12" THICK, AND COMPACTED. (GRANULAR MATERIAL)

CITY OF COLORADO SPRINGS
TRENCH BEDDING FOR FLEXIBLE PIPE

APPROVED BY

CITY ENGINEER

SCALE: NO SCALE DATE: JAN. 90 DRAWN: PL.B. SHEET: D - 32

SHAPED BEDDING
(Pipe - Arch)
Adopted from and in conformance with the State of Colorado Department of Highways with Revisions by the City of Colorado Springs Engineering Division

**Standard M-601-1**

JANUARY, 1982

---

**General Notes**

All work shall be done in accordance with the Standard Specifications except as the project may otherwise require. All concrete shall be Class "A" (Plain Concrete). All construction joints shall be thoroughly cleaned before fresh concrete is placed.

Construction joints shall be sealed with a 35-lb neat paster and shall extend through the entire cross section of the Box Culvert.

Splice quantities for longitudinal bars are not included.

---

**Section A-A**

**Section B-B**

---

**City of Colorado Springs**

**Single Concrete Box Culvert**

**Scale**

---

**Depth of toe wall to be increased if required by scour potential. Indicate dimension on plan.**
**STANDARD M-601-2**

**SECTION A-A**

- **Height of Full Design**
  - 10' 6-6-A: 6' 10' 6-6-B: 6' 10' 6-6-C: 6' 10' 6-6-D: 6' 10' 6-6-E: 6' 10' 6-6-F: 6' 10' 6-6-G: 6' 10' 6-6-H: 6' 10' 6-6-I: 6' 10' 6-6-J: 6'

**Table: Dimensions & Quantities**

- **Bar List**
  - **F-Bars (Cont)**

**Section B-B**

- **Headwall & Treadwall Quantities**
  - **Four Size Bares per Flow:**
    - 4
    - 5
    - 6
    - 7

**Notes:**
- All work shall be done in accordance with the Standard Specifications applicable to the project.
- All concrete shall be Class "A" (Plain Concrete).
- All concrete piles shall be immediately capped before form removal is completed.
- Construction joints shall be spaced at 3 ft. and shall be at least 1/8" thick.
- Concrete piles shall be embedded through the entire depth of the finished surface.
- Concrete quantities for longitudinal bars are not included.

**City of Colorado Springs**

**Double Concrete Box Culvert**

**General Notes**
- Concrete is to be mix designed at a yield of 18,000 psi, after 28 days. Records of concrete mix design should be submitted.
- All required concrete must be placed and cured as required.

**Revision History**
- January 1983

**Scale:**
- 1" = 80 ft.
- 1" = 50 ft.

**Date:**
- JAN 90
**Adopted from and in conformance with the State of Colorado Department of Highways with Revisions by the City of Colorado Springs Engineering Division**

---

**STANDARD M-601-3**

(JANUARY, 1982)

*Depth of toes wall to be increased if required by scour potential. Indicate dimension on plan.*

**Upstream vertical wall edge shall have a full height 5 x 5 x 3/8" angle attached with 6 inch Nelson studs. Hot dip galvanized.**

---

**DIMENSIONS & QUANTITIES**

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<tr>
<th>HEIGHT</th>
<th>TYPE</th>
<th>CLEAR SPAN</th>
<th>HYDRAULIC PRESSURE</th>
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**BAR LIST**

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**GENERAL NOTES**

All work shall be done in accordance with the Standard Specifications applicable to the project.

All concrete shall be Class "A" (No Cement). All construction joints shall be thoroughly cleaned before fresh concrete is placed.

Construction joints shall be spaced at 33 feet on centers and poured through the entire cross section of the box culvert.

Steel quantities for longitudinal bars are not included.

**DESIGN DATA**

*Sheet: 20,000 psi*

*Steel:
- 1,200 psi*
Adopted from and in conformance with the State of Colorado Department of Highways with Revisions by the City of Colorado Springs Engineering Division

**STANDARD M-601-20**
(JANUARY, 1962)

**DETAILED DESIGN TABLE**

**TYPICAL SECTION**

**QUANTITIES FOR WALL ONLY**

Concrete 0.049 cubic yd per ft
Reinforcement 0.43 ft lb per ft

**APRON TOE WALL**

**WITH CONCRETE APRON**

Re-bar: 3/8" x 8 ft

**GENERAL NOTES**

All work shall be done in accordance with the Standard Specifications applicable to the project

All concrete in contact shall be placed with 2% water

Wingwall backfill shall be done at 100% of maximum density

Shovel depth, if specified on plans, shall be not less than 8 ft

**TYPICAL CULVERT LAYOUT**

**WING WALLS FOR PIPE OR BOX CULVERT**

**CITY OF COLORADO SPRINGS**

**APPROVED BY**

**DATE:** JAN, 90  **DRAWN:** P L B  **SHEET:** D-36
TRIVIEW METROPOLITAN DISTRICT
STORM SEWER OUTFALL BASIN

SIDE CROSS SECTION

FRONT CROSS SECTION

COVER RIP-RAP WITH A MINIMUM OF
4" OF TOPSOIL. SEED WITH DISTRICT
APPROVED GRASS MIXTURE.

MIRAFI 140 OR EQUAL

T-1
RIP-RAP SIZES
FOR 15" THROUGH 21" PIPE

VELOCITY

$D_{50}$
RIP-RAP SIZES FOR 24" THROUGH 36" PIPE

VELOCITY

D$_{50}$
5. RIPRAP

Riprap has proven to be an effective means to deter erosion along channel banks, in channel beds, upstream and downstream from hydraulic structures, at bends, at bridges, and in other areas where erosive tendencies exist. Riprap is a popular choice for erosion protection because the initial installation costs are often less than alternative methods for preventing erosion. However, the designer needs to bear in mind that there are additional costs associated with riprap erosion protection since riprap installations require frequent inspection and maintenance. Wire enclosed riprap (gabion) in most cases requires complete renovation every 10 to 15 years.

One problem which the designer often neglects is the "erosive" effect of neighborhood children in urban areas on the riprap itself. It has been found by many engineers and public works officials that sometimes the riprap is almost completely lost within the first month or two after project completion. It is usually thrown into the water by the children purely for the sake of causing splashes. Increased police observance and meetings with neighborhood leaders have little effect. This non-hydraulic problem often makes the use of light or very light riprap impractical in urban areas.

In 1980 the Urban Drainage and Flood Control District staff began investigating riprap design and installation practices. Clear and concise procedures for design and installation were found to be lacking, and it was decided to develop a set of riprap design and installation guidelines for the District. Dr. William Hughes of the University of Colorado at Denver was retained by the District in 1981 to research the topic and to develop draft riprap criteria. The draft criteria was then distributed, on a trial basis, to engineering professionals in the Denver metropolitan area. This permitted the District staff to gain experience for approximately nine months with the draft documents.
The Type I and Type II bedding specifications shown in Table 5-3 were developed using the T-V filter criteria and the fact that bedding, which will protect an underlying noncohesive soil with a mean grain size of 0.045 mm will protect anything finer. Since the T-V filter criterion provides some latitude in establishing bedding gradations, it was possible to make the Type I and Type II bedding specifications conform with Colorado Division of Highways aggregate specifications. The Type I bedding in Table 5-3 is designed to be the lower layer in a two-layer filter for protecting fine-grained soils and has a gradation identical to Colorado Division of Highways Class A filter material (Section 703.09) except that it permits a slightly larger maximum rock fraction. When the channel is excavated in course sand and gravel (50 percent or more by weight retained on the #40 sieve), only the Type II filter is required. Otherwise, a two-layer bedding (Type I topped by Type II) is required. Alternatively, a single 12 inch layer of Type II bedding can be used except at drop structures. For required bedding thickness see Table 5-4. At drop structures a combination of filter fabric and Type II bedding is acceptable as an alternative to two-layer filter. The specifications for the T-V reverse filter relate the gradation of the protective layer (filter) to that of the bed material (base) by the following inequalities:

\[
\begin{align*}
D_{15}\text{(filter)} & \leq 5 \times D_{85}\text{(base)} \quad \text{(Equation 5-1)} \\
4 \times D_{15}\text{(base)} & \leq D_{15}\text{(filter)} \leq 20 \times D_{15}\text{(base)} \quad \text{(Equation 5-2)} \\
D_{50}\text{(filter)} & \leq 25 \times D_{50}\text{(base)} \quad \text{(Equation 5-3)}
\end{align*}
\]

where the capital "D" refers to the filter grain size and the lower case "d" to the base grain size. The subscripts refer to the percent by weight which is finer than the grain size denoted by either "D" or "d". For example, 15 percent of the filter material is finer than \(D_{15}\text{(filter)}\) and 85 percent of the base material is finer than \(D_{85}\text{(base)}\). Application of the T-V filter criteria is best described using an example (see Paragraph 5.7.1).
Before printing the final version of the criteria, the District retained Dr. Michael A. Stevens to provide an independent technical review. Dr. Stevens concluded that the basic document was technically sound and also offered suggestions to clarify the document and to make the text more consistent with commonly used terminology. The final version of this section is considered to be state-of-the-art as it is known today. Never-the-less changes are expected in the future as the technology continues to evolve.

5.1 Ordinary Riprap

Ordinary riprap, or simply riprap, refers to a protective blanket of large loose stones, which are usually placed by machine to achieve a desired configuration. The term ordinary riprap has been introduced to differentiate loose stones from grouted riprap and wire enclosed rock, which are discussed later.

Many factors govern the size of the rock necessary to resist the forces tending to move the riprap. For the riprap itself, this includes the size and weight of the individual rocks, the shape of the stones, the gradation of the particles, the blanket thickness, the type of bedding under the riprap, and the slope of the riprap layer. Hydraulic factors affecting riprap include the velocity, current direction, eddy action and waves.

Experience has shown that riprap failures result from undersized individual rocks in the maximum size range, improper gradation of the rock which reduces the interlocking of individual particles and improper bedding for the riprap which allows leaching of channel particles through the riprap blanket.

5.1.1 Rock Properties

Rock used for riprap or wire enclosed riprap should be hard, durable, angular in shape, and free from cracks, overburden, shale and organic matter. Neither breadth nor thickness of a single stone should be less than 1/3 its length and rounded stone should be avoided. The rock should sustain a loss of not more than 40 percent after 500 revolutions in an abrasion test (Los Angeles machine - ASTM C-535-69) and should sustain a loss of not more than 10 percent after
12 cycles of freezing and thawing (AASHTO test 103 for ledge rock procedure A). Rock having a minimum specific gravity of 2.65 is preferred; however, in no case should rock have a specific gravity less than 2.50. Classification and gradation for riprap are shown in Table 5-1 and Figure 5-1 and are based on minimum specific gravity of 2.50 for the rock. Because of its relatively small size and weight, riprap types VL and L must be buried with native top soil and revegetated to protect the rock from vandalism.

5.1.2 Grouted Riprap

Grouted riprap provides a relatively impervious channel lining which is less subject to vandalism than dumped riprap. Grouted riprap requires less routine maintenance by reducing silt and trash accumulation and is particularly useful for lining low flow channels and steep banks. The appearance of grouted riprap is enhanced by exposing the tops of individual stones and by cleaning the projecting rocks with a wet broom. Grouted riprap should meet all the requirements for ordinary riprap except that the smallest rock fraction (smaller than the 10 percent size) should be eliminated from the gradation. A reduction of riprap size by one size designation is permitted for grouted rock.

As with ordinary riprap, grouted riprap should be placed on an adequate bedding. The grout should contain air entrainment, have a 28-day strength of at least 2400 pounds per square inch and should have a high slump (5 to 7 inches) in order to penetrate either the full depth of the riprap layer or at least 2 feet where the riprap layer is thicker than 2 feet. Grout penetration may be accomplished by rodding, vibrating, or pumping of the grout into the riprap voids. Concrete having maximum aggregate size of 3/4-inches may be substituted for grout when using Type M riprap or larger riprap. Weep holes should be provided at least every 4 to 6 feet at the toe of channel slopes and channel drops to reduce uplift forces on the grouted channel lining.
FIGURE 5-1. GRADATION OF ORDINARY RIPRAP
Table 5-1

CLASSIFICATION AND GRADATION OF ORDINARY RIPRAP

<table>
<thead>
<tr>
<th>Riprap Designation</th>
<th>% Smaller Than Given Size By Weight</th>
<th>Intermediate Rock Dimension (Inches)</th>
<th>(d_{50}) * (Inches)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type VL</td>
<td>70-100</td>
<td>12</td>
<td>6**</td>
</tr>
<tr>
<td></td>
<td>50-70</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>35-50</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-10</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Type L</td>
<td>70-100</td>
<td>15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50-70</td>
<td>12</td>
<td>9**</td>
</tr>
<tr>
<td></td>
<td>35-50</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-10</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Type M</td>
<td>70-100</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50-70</td>
<td>18</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>35-50</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-10</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Type H</td>
<td>100</td>
<td>30</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50-70</td>
<td>24</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>35-50</td>
<td>18</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2-10</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Type VH</td>
<td>100</td>
<td>42</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50-70</td>
<td>33</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>35-50</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>2-10</td>
<td>9</td>
<td></td>
</tr>
</tbody>
</table>

\*\(d_{50}\) = Mean particle size

** Bury types VL and L with native top soil and revegetate to protect from vandalism.

5.2 Wire Enclosed Rock

Wire enclosed rock refers to rocks that are bound together in a wire basket so that they act as a single unit. One of the major advantages of wire enclosed rock is that it provides an alternative in situations where available rock sizes are too small for ordinary riprap. Another advantage is the versatility that results from the regular geometric shapes of wire enclosed rock. The rectangular blocks and mats can be fashioned into almost any shape that can be
formed with concrete. The durability of wire enclosed rock is generally limited by the service life of the galvanized binding wire which, under normal conditions, is considered to be about 15 years. Water carrying silt, sand or gravel can reduce the service life of the wire; also water which rolls or otherwise moves cobbles and large stones breaks the wire with a hammer and anvil action and considerably shortens the life of the wire. The wire has been found to be susceptible to corrosion by various chemical agents and is particularly affected by high sulfate soils. If corrosive agents are known to be in the water or soil, a plastic coated wire should be specified.

Wire enclosed rock is not maintenance free and must be periodically inspected to determine whether the wire is sound. If breaks are found while they are still relatively small, they may be patched by weaving new strands of wire into the wire cage. Wire enclosed rock installations have been found to attract vandalism. Flat mattress surfaces seem to be particularly susceptible to having wires cut and stones removed. It is recommended that, where possible, mattress surfaces be buried, as it has been found that wire enclosed rock buried under a few inches of soil is less prone to vandalism. Wire enclosed rock installations need to be inspected at least once a year under the best circumstances and may require inspection every three months in vandalism prone areas in conjunction with a regular maintenance program. Mattresses on sloping surfaces must be securely anchored to the surface of the soil as discussed in Section 5.5.3.

Rock filler for the wire baskets should meet the rock property requirements for ordinary riprap. Minimum rock sizes and basket characteristics are shown in Table 5-2. The maximum stone size should not exceed 2/3 the basket depth or 12 inches, whichever is smaller.
Table 5-2
GABION BASKETS
(Standard U.S.A. Sizes)

<table>
<thead>
<tr>
<th>Drainage manual designation</th>
<th>Letter code</th>
<th>length</th>
<th>width</th>
<th>depth</th>
<th>Number of diaphragms</th>
<th>Capacity cubic yards</th>
<th>Minimun rock dimensi</th>
</tr>
</thead>
<tbody>
<tr>
<td>G36</td>
<td>A</td>
<td>6'</td>
<td>3'</td>
<td>3'</td>
<td>1</td>
<td>2</td>
<td>4&quot;</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>9'</td>
<td>3'</td>
<td>3'</td>
<td>2</td>
<td>3</td>
<td>4&quot;</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>13'</td>
<td>3'</td>
<td>3'</td>
<td>3</td>
<td>4</td>
<td>4&quot;</td>
</tr>
<tr>
<td>G18</td>
<td>D</td>
<td>6'</td>
<td>3'</td>
<td>1'</td>
<td>1</td>
<td>1</td>
<td>4&quot;</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>9'</td>
<td>3'</td>
<td>1'</td>
<td>2</td>
<td>1.5</td>
<td>4&quot;</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>13'</td>
<td>3'</td>
<td>1'</td>
<td>3</td>
<td>2</td>
<td>4&quot;</td>
</tr>
<tr>
<td>G12</td>
<td>G</td>
<td>6'</td>
<td>3'</td>
<td>1'</td>
<td>1</td>
<td>0.66</td>
<td>4&quot;</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td>9'</td>
<td>3'</td>
<td>1'</td>
<td>2</td>
<td>1</td>
<td>4&quot;</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>13'</td>
<td>3'</td>
<td>1'</td>
<td>3</td>
<td>1.33</td>
<td>4&quot;</td>
</tr>
<tr>
<td>SLOPE MATTRESS</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SM9</td>
<td>T</td>
<td>9'</td>
<td>6'</td>
<td>0'-9&quot;</td>
<td>5</td>
<td>1.80</td>
<td>3&quot;</td>
</tr>
<tr>
<td></td>
<td>U</td>
<td>12'</td>
<td>6'</td>
<td>0'-9&quot;</td>
<td>6</td>
<td>2.20</td>
<td>3&quot;</td>
</tr>
</tbody>
</table>

5.3 Bedding Requirements

Long term stability of riprap and gabion erosion protection is strongly influenced by proper bedding conditions. A large percentage of all riprap failures are directly attributable to bedding failures, which is particularly disturbing in light of the fact that over half of all riprap installations experience some degree of failure within 10 years of construction.

A properly designed bedding provides a buffer of intermediate sized material between the channel bed and the riprap to prevent leaching of channel particles through the voids in the riprap. Two types of bedding are in common use: 1) a granular bedding filter and 2) filter fabric.

5.3.1 Granular Bedding

Two methods for establishing gradation requirements for granular bedding are described in this section. The first, a one or two layer bedding, shown in Table 5-3 is adequate for most ordinary riprap,
grouted riprap or wire encased riprap applications. The second utilizes a design procedure developed by Terzaghi, which is referred to as the T-V (Terzaghi-Vicksburg) design (7)(19). The T-V filter criteria establishes an optimum bedding gradation for a specific channel soil. The latter requires channel soil information, including a gradation curve, while the Type I and Type II bedding specifications given in Table 5-3 (and Figure 5-2) are applicable whether or not soil information is available.

<table>
<thead>
<tr>
<th>U. S. Standard Sieve Size</th>
<th>Percent Weight By Passing Type I</th>
<th>Square Mesh Sieves Type II</th>
</tr>
</thead>
<tbody>
<tr>
<td>3&quot;</td>
<td>-</td>
<td>90 - 100</td>
</tr>
<tr>
<td>1-1/2&quot;</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>3/4&quot;</td>
<td>-</td>
<td>20 - 90</td>
</tr>
<tr>
<td>3/8&quot;</td>
<td>100</td>
<td>-</td>
</tr>
<tr>
<td>#4</td>
<td>95 - 100</td>
<td>0 - 20</td>
</tr>
<tr>
<td>#16</td>
<td>45 - 80</td>
<td>-</td>
</tr>
<tr>
<td>#50</td>
<td>10 - 30</td>
<td>-</td>
</tr>
<tr>
<td>#100</td>
<td>2 - 10</td>
<td>-</td>
</tr>
<tr>
<td>#200</td>
<td>0 - 2</td>
<td>0 - 3</td>
</tr>
</tbody>
</table>
Table 5-4
THICKNESS REQUIREMENTS FOR GRANULAR BEDDING

<table>
<thead>
<tr>
<th>Riprap Designation</th>
<th>Minimum Bedding Thickness (Inches)</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Fine Grained Soils*</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Type I</td>
<td>Type II</td>
<td></td>
</tr>
<tr>
<td>L, G, SM</td>
<td>4</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>M</td>
<td>4</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>H</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>VH</td>
<td>4</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Course Grained Soils**</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Type II</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*May substitute one 12 inch layer of Type II bedding. Substitution of one layer of Type II bedding shall not be permitted at drop structures. Use of a combination of filter fabric and Type II bedding at drop structures is acceptable, see Section 5.3.2 for use of filter fabric at drop structures.

**Fifty percent or more by weight retained on the #40 sieve.

5.3.2 Filter Fabric

Filter fabric is not a complete substitute for granular bedding. Filter fabric provides filtering action only perpendicular to the fabric and has only a single equivalent pore opening between the channel bed and the riprap. Filter fabric has a relatively smooth surface which provides less resistance to stone movement. As a result, it is recommended the use of filter fabric be restricted to slopes no steeper than 2.5h to lv. Tears in the fabric greatly reduce its effectiveness so that direct dumping of riprap on the filter fabric is not allowed and due care must be exercised during construction. Nonetheless, filter fabric has proven to be an adequate replacement for granular bedding in many instances. Filter fabric provides an adequate bedding for channel linings along uniform mild sloping channels where leaching forces are primarily perpendicular to the fabric.

At drop structures and sloped channel drops, where seepage forces may run parallel with the fabric and cause piping along the bottom surface of the fabric, special care is required in the use of filter
fabric. Seepage parallel with the fabric might be reduced by folding the edge of the fabric vertically downward about 2 feet (similar to a cutoff wall) at 12-foot intervals along the installation, particularly at the entrance and exit of the channel reach. Filter fabric has to be lapped a minimum of 12 inches at roll edges with upstream fabric being placed on top of downstream fabric at the lap.

Fine silt and clay has been found to clog the openings in filter fabric. This prevents free drainage which increases failure potential due to uplift. For this reason, a double granular filter is often a more appropriate bedding for fine silt and clay channel beds. See Figures 5-3 a through 5-3 c for details on acceptable use of filter fabric as bedding.

5.4 Channel Linings

Channel linings constructed from ordinary riprap, grouted riprap, or wire encased rock to control channel erosion have been found to be cost effective where channel reaches are relatively short (less than 1/4 mile). Situations for which riprap linings might be appropriate are: 1) where major flows, such as the 100-year flood are found to produce channel velocities in excess of allowable non-eroding values (5 feet per second for sandy soil conditions and 7 feet per second in erosion resistant soils); 2) where channel side slopes must be steeper than 3:1; 3) for low flow channels, and 4) where rapid changes in channel geometry occur such as channel bends and transitions. Design criteria applicable to these situations are presented in this section. Section 5.4 emphasizes design requirements associated with ordinary riprap, while Section 5.5 contains additional design considerations specifically related to wire enclosed rock. Both Sections 5.4 and 5.5 are valid only for subcritical flow conditions where the Froude number is 0.8 or less.

5.4.1 Roughness Coefficient

The Manning's roughness coefficient (n) for hydraulic computations has been found to be about 0.035 for wire enclosed rock and may
be estimated for ordinary riprap using:

\[ n = 0.0395 \frac{d_{50}}{1/6} \]

in which \( d_{50} \) = the mean stone size in feet.

This equation does not apply to grouted riprap (\( n = 0.023 \) to \( 0.030 \)), or to very shallow flow (hydraulic radius is less than or equal to 2 times the maximum rock size) where the roughness coefficient will be greater than indicated by the formula.

### 5.4.2 Rock Size and Lining Dimensions

Table 5-5 summarizes riprap requirements for a stable channel lining based on the following relationship which resulted from Smith and Murray's model studies (24):

\[
\frac{V S^{0.17}}{d_{50}^{0.5} (S_s - 1)^{0.66}} = 4.5 \quad \text{(Equation 5-4)}
\]

in which, \( V \) = mean channel velocity in feet per second

\( S \) = longitudinal channel slope in feet per foot

\( S_s \) = Specific gravity of rock (minimum \( S_s = 2.50 \))

\( d_{50} \) = rock size in feet for which 50 percent of the riprap by weight is smaller.

The rock sizing requirements in Table 5-5 are based on the rock having a specific gravity of 2.5 or more. Rock having specific gravity less than 2.5 is considered unacceptable.

Table 5-5 represents a significant departure from past practices by recognizing that rock size does not need to be increased for steeper channel side slopes, provided the side slopes are no steeper than 2h:1v (24). Rock lined side slopes steeper than 2h:1v are considered unacceptable because of stability, safety, and maintenance considerations. Proper bedding is required both along the side slopes and the channel bottom for a stable lining. The riprap blanket thickness should be at least 1.75 times \( d_{50} \) (at least 2.0 times \( d_{50} \) in sandy soils) and should extend up the side slopes at least one foot above the design water surface. At the upstream and downstream termination of a riprap lining, the thickness should be increased 50 percent for at least 3 feet to prevent under cutting.
### Table 5-5

RIPRAP REQUIREMENTS FOR CHANNEL LININGS **

<table>
<thead>
<tr>
<th>( V S^{0.17} / (S_s - 1)^{0.66} ) (ft(^3)/sec)</th>
<th>Rock Type ***</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.4 to 3.2</td>
<td>VL</td>
</tr>
<tr>
<td>3.3 to 3.9</td>
<td>L</td>
</tr>
<tr>
<td>4.0 to 4.5</td>
<td>M</td>
</tr>
<tr>
<td>4.6 to 5.5</td>
<td>H</td>
</tr>
<tr>
<td>5.6 to 6.4</td>
<td>VH</td>
</tr>
</tbody>
</table>

* Use \( S_s = 2.5 \) unless the source of rock and its densities are known at the time of design.

** Table valid only for Froude number of 0.8 or less and side slopes no steeper than 2h:1v.

*** Type VL and L riprap shall be buried after placement to reduce vandalism.

SM9 slope mattress with toe protection may be substituted for Type VL or L riprap.

G12 gabion with toe protection may be substituted for Type M and Type H riprap.

### 5.4.3 Toe Protection

Where only the channel sides are to be lined, additional riprap is needed to provide for long term stability of the lining. In this case, the riprap blanket should extend at least 3 feet below the existing channel bed and the thickness of the blanket below the existing channel bed increased to at least 3 times \( d_{50} \) to accommodate possible channel scour during floods (see Figure 5-4a). For sandy soils, consult specific criteria for channels on sandy soils. If wire enclosed rock lining is used, the toe must be protected by placing riprap at the toe. This is needed to protect against frequently occurring abrasion, (see Figure 5-4b and 5-4c).
5.4.4 Channel Bends

The potential for erosion increases along the outside bank of a channel bend due to the acceleration of flow velocities on the outside part of the bend. Thus, it is often necessary to provide erosion protection in channels which otherwise would not need protection. In erosion resistant soils, no extra protection is required by these criteria along bends where the radius is greater than 2 times the top width (as measured for the major flows) but in no case less than 100 feet.

For bank protection requirements in sandy soils, consult the specific criteria for channels on sandy soils. However, for channels in erosion resistant soils not requiring riprap protection along straight sections, channel bends with radii smaller than stated above require Type L or SM9 riprap protection. As stipulated earlier, such riprap needs to be covered with native soil and revegetated in accordance with Section 5.1.1. The minimum allowable radius for a riprap lined bend is 1.2 times the top width of the design flow water surface and in no case less than 50 feet. The riprap protection should be placed along the outside of the bank and should extend downstream from the bend a distance equal to the length of the bend.

Where the mean channel velocity exceeds the allowable non-eroding velocity so that riprap protection is required for straight channel sections, increase the rock size by one category (e.g., Type L to Type M) around bends. The minimum allowable radius for a riprap lined bend in this case is also 1.2 times the top width of the design flow water surface.

5.4.5 Transitions

Scour potential is amplified by turbulent eddies in the vicinity of rapid changes in channel geometry such at transitions and bridges. Table 5-5 may be used for selecting riprap protection for subcritical transitions (Froude numbers 0.8 or less) by increasing the channel velocity by twenty (20%) percent.
Since the channel velocity varies through a transition, the maximum velocity in the transition should be used in selecting riprap size after it has been increased by 20%.

Protection should extend upstream from the transition entrance at least 5 feet and extend downstream from the transition exit at least 10 feet.

5.5 Wire Enclosed Riprap Linings

The geometric properties of wire enclosed rock permit placement in areas where ordinary riprap is either difficult or impractical to place. Proper design and construction is important to successful operation and lifetime performance. Figures 5-5a and 5-5b depict some of the more common ways wire enclosed rock is configured along channel banks. However, use of wire enclosed riprap lining is is not encouraged, particularly in areas exposed to annual floods, and it is recommended that ordinary riprap be used whenever it is feasible.

5.5.1 Side Slope Steeper Than 2h to 1v

Where channel side slopes must exceed 2h to 1v, gabion baskets (G36) may be stacked to form a retaining wall as well as erosion protection along the channel banks as shown in Figure 5-5b. Adjacent baskets should be tied together with heavy gauge wire and adequate protection against channel bed degradation must be provided at the toe of the lining. Stacked baskets must be sloped, or stepped into the bank as shown in Figure 5-5b. Vertical stacking is not acceptable.

5.5.2 Counterforts

Channel linings should be tied to the channel banks with gabion (G36) counterforts at least every 12 feet. Counterforts should be keyed at least 12 inches into the existing banks with slope mattress
linings (see Figure 5-5a) and should be keyed at least 3 feet by turning the counterfort gabions end-wise when the lining is designed to serve as a retaining wall (see Figure 5-5b).

5.5.3 Slope Mattress Staking

Mattresses and flat gabions on channel side slopes need to be tied to the banks by 2-inch diameter steel pipes driven 4 feet into tight solid (clay) and 6 feet into loose soil (sand) (see Figure 5-5a). The pipes should be located at the inside corners of basket diaphragms along an upslope (highest) basket wall, so that the stakes are an integral part of the basket. The exact spacing of the stakes depends upon the configuration of the baskets, however the following is the suggested minimum spacing: Stakes every six feet along and down the slope, for slopes 2.5 to 1 and steeper and every 9 feet along and down the slope for slopes flatter than 2.5 to 1. Counterforts are optional with slope mattress linings. Slope mattress staking, however, is required, whether or not counterforts are used.

5.6 Erosion Protection at Conduit Outlets

Scour resulting from highly turbulent rapidly decelerating flow is a common problem at conduit outlets. The following riprap protection is suggested for outlet Froude numbers up to 2.5 (i.e., Froude parameters \(Q/D^{2.5}\) or \(Q/WH^{1.5}\) up to 14 ft. \(0.5/\text{sec}\)) where the outlet of the conduit slope is parallel with the channel gradient and the conduit outlet invert is flush with the riprap channel protection. Here \(Q\) is the discharge in cubic feet per second, \(D\) is the diameter of a circular conduit in feet and \(W\) and \(H\) are the width and height of a rectangular conduit in feet.

5.6.1 Configuration of Riprap Protection

Figure 5-6 illustrates a typical riprared basin at a conduit outlet. The additional thickness of the riprap just downstream from the outlet is to assure protection from extreme flow conditions which might precipitate rock movement in this region. Note that protection is required under the conduit barrel and an end slope is provided to accommodate degradation of the downstream channel.
5.6.2 Required Rock Size

The required rock size may be selected from Figure 5-7 for circular conduits and from Figure 5-8 for rectangular conduits. Figure 5-7 is valid for \( Q/D^{2.5} \) of 6.0 or less and Figure 5-8 is valid for \( Q/WH^{1.5} \) of 8.0 or less. The parameters in these two figures are:

a. \( Q/D^{1.5} \) or \( Q/WH^{0.5} \) in which \( Q \) is the design discharge in cubic feet per second and \( D \) is a circular conduit diameter in feet and \( W \) and \( H \) are the width and height of a rectangular conduit in feet.

b. \( Y_t/D \) or \( Y_t/H \) in which \( Y_t \) is the tailwater depth in feet, \( D \) is the diameter of a circular conduit and \( H \) is the height of a rectangular conduit in feet. In cases where \( Y_t \) is unknown or a hydraulic jump is suspected downstream of the outlet, use \( Y_t/D = Y_t/H = 0.40 \) when using Figures 5-7 and 5-8.

c. The riprap size requirements in Figures 5-7 and 5-8 are based on the non-dimensional parametric equations 5-5 and 5-6 (11)(25).

Circular Culvert:

\[
(d_{50}/D)(Y_t/D)^{1.2} / (Q/D^{2.5}) = 0.023 \quad \text{(Equation 5-5)}
\]

Rectangular Culvert:

\[
(d_{50}/D)(Y_t/H)^{0} / (Q/WH^{1.5}) = 0.014 \quad \text{(Equation 5-6)}
\]

The rock size requirements were determined assuming that the flow in the culvert barrel is not supercritical. It is possible to use Equations 5-5 and 5-6 when the flow in the culvert is less than pipe full and is supercritical if the value of \( D \) or \( H \) is modified for use in Figures 5-7 and 5-8. Whenever the flow is supercritical in the culvert, substitute \( D_a \) for \( D \) and \( H_a \) for \( H \), in which \( D_a \) is defined as

\[
D_a = \frac{1}{2}(D + Y_n) \quad \text{(Equation 5-7)}
\]

in which maximum \( D_a \) shall not exceed \( D \), and

\[
H_a = \frac{1}{2}(H + Y_n) \quad \text{(Equation 5-8)}
\]

in which maximum \( H_a \) shall not exceed \( H \), and

\[
D_a = A \text{ parameter to be used in Figure 5-7}
\]

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whenever the culvert flow is supercritical.

\[ D = \text{Diameter of a circular culvert in feet.} \]

\[ H_a = \text{A parameter to be used in Figure 5-8 whenever the culvert flow is supercritical.} \]

\[ H = \text{Height of a rectangular culvert in feet.} \]

\[ Y_n = \text{Normal depth of supercritical flow in the culvert.} \]

### 5.6.3 Extent of Protection

The length of the riprap protection downstream from the outlet depends on the degree of protection desired. If it is to prevent all erosion, the riprap must be continued until the velocity has been reduced to an acceptable value. For purposes of outlet protection during major floods the acceptable velocity is set at 5.5 fps for very erosive soils and at 7.7 fps for erosion resistant soils. The rate at which the velocity of a jet from a conduit outlet decreases is not well known. For the procedure recommended here it is assumed to be related to the angle of lateral expansions, \( \theta \), of the jet. The velocity is related to the expansion factor, \( (1/(2 \tan \theta)) \), which may be determined directly using Figure 5-9 or 5-10.

Assuming that the expanding jet has a rectangular shape:

\[ L = \frac{1}{(2 \tan \theta)} \left( A_t / Y_t - W \right) \]  \hspace{1cm} (Equation 5-9)

where:

\[ L = \text{length of protection in feet,} \]

\[ W = \text{width of the conduit in feet (use diameter for circular conduits),} \]
\[ Y_t = \text{tailwater depth in feet}, \]
\[ \theta = \text{the expansion angle of the culvert flow}. \]
\[ A_t = \frac{Q}{V} \quad \text{(Equation 5-10)} \]
\[ Q = \text{design discharge in cubic feet per second} \]
\[ V = \text{the allowable non-eroding velocity in the downstream channel in feet per second}. \]
\[ A_t = \text{required area of flow at allowable velocity in square feet}. \]

In certain circumstances, Equation 5-9 may yield unreasonable results. Therefore in no case should \( L \) be less than 3D or 3H, nor does \( L \) need to be greater than 10D or 10H whenever the Froude parameter \( Q/WH^{1.5} \) or \( Q/D^{2.5} \) is less than 8 or 6 respectively. Whenever the Froude parameter is greater than these maximums, increase the maximum \( L \) required by one-fourth \( D \) or \( H \) for each whole number the Froude parameter is greater than 8 or 6 for rectangular or circular pipe respectively.

5.6.4 Multiple Conduit Installations

The procedures outlined in Sections 5.6.1, 5.6.2 and 5.6.3 can be used to design outlet erosion protection for multi-barrel culvert installations, by hypothetically replacing the multiple barrels with a single hydraulically equivalent rectangular conduit. The dimensions of the equivalent conduit may be established as follows: First, distribute the total discharge, \( Q \), among the individual conduits. Where all the conduits are hydraulically similar and identically situated, the flow can be assumed to be equally distributed, otherwise, the flow through each barrel must be computed. Next, compute the Froude parameter \( Q_i/D_i^{2.5} \) (circular conduit) or \( Q_i/W_iH_i^{1.5} \) (rectangular conduit), where the subscript \( i \) indicates the discharge and dimensions associated with an individual conduit. If the installation includes dissimilar conduits, select the conduit with the largest value of the Froude
parameter to determine the dimensions of the equivalent conduit. Make
the height of the equivalent conduit, \( H_e \), equal to the height, or
diameter, of the selected individual conduit. The width of the equiv-
alent conduit, \( W_e \), is determined by equating the Froude parameter from
the selected individual conduit with the Froude parameter associated
with the equivalent conduit, \( Q/W_e H_e^{1.5} \).

5.7 Examples

5.7.1 Example - Design of Granular Bedding

Given: Sandy-silt channel bed with gradation shown by the
solid line in Figure 5-11.

Find: The gradation band for granular bedding required to
protect the given sandy-silt channel bed.

Step 1: From the gradation curve read:

\[
\begin{align*}
    d_{15}(\text{base}) & = 0.016 \text{ mm} \\
    d_{50}(\text{base}) & = 0.051 \text{ mm} \\
    d_{85}(\text{base}) & = 0.10 \text{ mm}
\end{align*}
\]

Step 2: The upper limit of \( D_{15}(\text{filter}) = 5 \times d_{85}(\text{base}) \)
(Equation 5-1, the upper limit of \( D_{15}(\text{filter}) =
5 \times 0.1 = 0.5 \text{ mm} \)).

Step 3: The upper limit of \( D_{15}(\text{filter}) = 20 \times d_{15}(\text{base}) \)
(Equation 5-2, the upper limit of \( D_{15}(\text{filter}) = 20 \times
0.016 = 0.32 \text{ mm} \)).

Since \( 0.32 \text{ mm} < 0.5 \text{ mm} \), requirement 2 controls. The upper
limit for \( D_{15}(\text{filter}) = 0.32 \text{ mm} \).

Step 4: The lower limit for \( D_{15}(\text{filter}) = 4 \times d_{15} \) (Equation
5-2, the lower limit for \( D_{15}(\text{filter}) = 4 \times 0.016 =
0.064 \text{ mm} \)).
Step 5: The upper limit for $D_{50}(\text{filter}) = 25 \times d_{50}$ (Equation 5-3, the upper limit for $D_{50}(\text{filter}) = 25 \times 0.051 = 1.28$ mm.

Step 6: Plot the results from Steps 2 through 5 as shown on Figure 5-11.

Step 7: Sketch the upper and lower limits of the gradation requirements for the lowest layer of the bedding. Use the shape of the sandy-silt gradation curve and the plotted points to establish the limits as shown by the dashed lines on Figure 5-11.

Step 8: Establish a gradation for the lowest bedding layer which fits within the gradation band from Step 7.

Step 9: Repeat Steps 1 through 8 using the gradation curve from Step 8 as the base; to establish the required gradation band for the second layer of the bedding. Usually two layers are sufficient.

Step 10: Set the granular bedding thickness of each layer to the thickness of each layer specified in Table 5-4.

5.7.2 Example - Single Conduit Outlet Protection

Given: 72 inch (6-ft) diameter culvert at $S_0 = 0.010$ ft/ft and $n = 0.012$.

D = 6 ft

Q = 500 ft$^3$/s (pipe full flow)

Tailwater depth (normal depth downstream) = 3.0 ft.

Allowable channel velocity downstream = 5.5 ft/s.
Q = 270 ft$^3$/s

Tailwater depth = 2.1 ft

Allowable channel velocity downstream = 7.7 ft/s

**Step 1:** Determine flow in each conduit and determine if they are flowing at supercritical depths.

Q = 270/3 = 90ft$^3$/s

Critical depth at 90ft$^3$/s = 1.02 ft

Normal depth $Y_n$ at 90 ft$^3$/s is pipe full flow.

Therefore flow is subcritical and no adjustment is needed to the diameter when using Figure 5-8.

**Step 2:** Compute Froude Parameter

$$F = \frac{Q}{D^{2.5}} = \frac{90}{3^{2.5}} = 5.77.$$ 

**Step 3:** Set height of equivalent rectangular conduit

$H_e = D = 3$ ft

**Step 4:** Calculate the width of an equivalent rectangular culver $W_e$ by equating Froude Parameters using $H_e = 3.0$ ft.

$$\frac{Q}{W_e H_e^{1.5}} = 5.77$$

or

$$W_e = \frac{270}{(5.77)(3)^{1.5}} = 9 \text{ ft}$$

**Step 5:** Determine type of riprap

$$Y_t/H_e = 2.1/3.0 = 0.7$$

$$Q/W_e H_e^{0.5} = 270/(9\times3^{0.5}) = 17.3$$

From Figure 5-8: Type L riprap

From Table 5-1: $d_{50} = 9 \text{ in}$
Step 6: Determine the expansion factor

\[
\frac{Q}{3^{3/2}} = \frac{270}{(9)(3)^{1.5}} = 5.77
\]

We \( H_e \) from Figure 5-10: \( 1/(2\tan \theta) = 4.3 \)

Step 7: Calculate length of protection

\[
A_t = \frac{270}{7.7} = 35.1 \text{ ft}^2
\]

\[
L = 4.3(35.1/2.1 - 9.0) = 33 \text{ ft}
\]

(Equation 5-10)

(Equation 5-9)

Step 8: Check if maximum or minimum limits govern

Since \( Q/D^{2.5} \) is less than 6.0, then

\[
L_{\text{max}} = 10H = 10(3) = 30 \text{ ft}
\]

Therefore, use \( L = 30 \text{ ft} \) for basin length.

Step 9: Determine maximum riprap depth

From Figure 5-6, maximum depth is \( 2d_{50} = 2(.75) = 1.50 \)

Example 2 - Dissimilar Pipes

Given: Double 36 inch (3 ft) culvert

Single 48 inch (4 ft) culvert

All pipes at \( S_o = 0.030 \text{ ft/ft} \) and \( n = 0.012 \)

All outlet inverts are at the same elevation. This procedure can be applied only to such cases. If inverts are not at the same elevation, suggest using a concrete energy dissipator.

\( Q = 315 \text{ ft}^3/\text{s} \)

Headwater depth = 8 ft

Tailwater depth = 3.0 ft

Allowable channel velocity downstream = 7.7 ft/s

Step 1: Determine the flow in each conduit

Assume inlet control governs

\[
\frac{HW}{D_1} = \frac{8}{4} = 2; \quad \frac{HW}{D_2} = \frac{8}{3} = 2.67
\]
From highway culvert nomographs for circular pipe having a square edged headwall type entrance

\[ Q_1 = 145 \text{ ft}^3/\text{s}; \quad Q_2 = 85 \text{ ft}^3/\text{s} \]

**Step 2:** Determine if any of the pipes are flowing at supercritical depths.

Critical depth for a 48 in circular pipe at 145 ft$^3$/s is 3.5 ft. Normal depth ($Y_n$), is 2.12 ft. Therefore, this pipe is flowing supercritical.

Critical depth for a 36 inch circular pipe at 85 ft$^3$/s is 2.79 ft. Normal depth ($Y_n$), is 1.80 ft. Therefore, this pipe is flowing supercritical and inlet control assumption in Step 2 is also valid.

**Step 3:** Since the culverts are at supercritical flow, determine the modified pipe heights.

For the 48 in pipe

\[ D_a = \frac{1}{2} (4.0 + 2.12) = 3.06 \text{ ft} \quad \text{(Equation 5-7)} \]

For the 36 in pipe

\[ D_a = \frac{1}{2} (3.0 + 1.80) = 2.40 \text{ ft} \]

**Step 4:** Compute Froude Parameters and determine equivalent rectangular height

\[ F_1 = \frac{145}{3.06^{2.5}} = 8.85 \]
\[ F_2 = \frac{85}{2.40^{2.5}} = 9.53 \]

$F_2$ governs, therefore use $H_a = D_a = 2.40$ ft. Note that because $D_a$ is less than the tailwater and the pipe is flowing at supercritical depth, a hydraulic jump downstream of outlet is suspected. Also note that $F_1$
and $F_2$ exceeds the upper limit of 6.0 for circular pipe and the use of riprap or Figures 5-7 and 5-8 would not normally be acceptable. However, for the sake of illustrating the procedure this example utilizes these two Figures for rock size selection.

**Step 5:** Calculate width of equivalent rectangular culvert $W_e$ for the 3 foot pipe by equating Froude Parameters using

$$H_e = 2.40 \text{ ft.}$$
$$\frac{Q}{W_e H_e^{1.5}} = 9.53$$
$$W_e = \frac{315}{(9.53)(2.4)^{1.5}} = 8.9 \text{ ft.}$$

**Step 6:** Determine type of riprap

$$Y_t/H_e = 3.0/2.40 > 1.0$$

Tailwater is greater than approach flow and a hydraulic jump is suspected, therefore in accordance with Paragraph 5.6.2, set $Y_t/H_e = 0.40$ for use with Figure 5-8.

$$\frac{Q}{(W_e H_e^{0.5})} = \frac{315}{(8.9 \times 2.40^{0.5})} = 22.8$$

From Figure 5-8: Type M riprap

From Table 5-1: $d_{50} = 12 \text{ in}$

Note the qualification in Step 4 of this example

**Step 7:** Determine expansion factor $1/(2\tan \theta)$.

$$\frac{Q}{W_e H_e^{1.5}} = 9.53$$
$$Y_t/H_e = \frac{2.4/1.76}{2.40} = 1.36$$

Note that the value of these two parameters is beyond the range of Figure 5-10. Never-the-less, a value of $1/(2\tan \theta)$ is chosen using

$$\frac{Q}{W_e H_e^{1.5}} = 6$$

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and

\[ \frac{y_t}{H_e} = 1.0 \]

Set \( \frac{1}{(2\tan \theta)} = 5.6 \)

**Step 8:** Determine length of protection

\[ A_t = \frac{315}{7.7} = 40.9 \text{ ft}^2 \]  \hspace{2cm} \text{(Equation 5-10)}

\[ L = 5.6 \left(\frac{40.9}{3.0} - 8.9\right) = 26.5 \text{ feet} \] \hspace{2cm} \text{(Equation 5-9)}

**Step 9:** Check if maximum limit governs using the tallest culvert of the three. Since the Froude Parameter for the controlling circular pipe is greater than 6, the upper limit must be increased by one-fourth for each whole Froude Parameter greater than 6. Thus,

\[ L_{max} = (10 + 0.25 (9.53 - 6))H \]

or

\[ L_{max} = 10.9H \]

\[ L_{max} = 10.9(4.0) = 43.6 \text{ ft} \]

Since the basin length in Step 8 is less than \( L_{max} \), use basin length \( L = 26.5 \text{ ft} \).
Step 1: Determine the required type of riprap for erosion protection.

First check to see if culvert is supercritical. Since the pipe is flowing full \( D_a = D = 6 \text{ ft} \)

Then,

\[
\frac{Y_t}{D} = \frac{3.0}{6.0} = 0.5 \\
Q/D^{1.5} = \frac{500}{6^{1.5}} = 34
\]

From Figure 5-7 -- Type VH riprap will be required

From Table 5-1 -- \( d_{50} = 24 \text{ in} \)

Step 2: Determine the expansion factor \( 1/(2\tan \theta) \).

\[
Q/D^{2.5} = \frac{500}{6^{2.5}} = 5.67
\]

From Figure 5-9 -- \( 1/(2\tan \theta) = 2.8 \)

Step 3: Determine the length of riprap protection

\[ A_t = \frac{500}{5.5} = 91 \text{ ft}^2 \quad \text{(Equation 5-10)} \]

\[ L = 2.8 \left( \frac{91}{3} - 6 \right) = 68 \text{ ft} \quad \text{(Equation 5-9)} \]

Step 4: Check if maximum or minimum limit governs

Since \( Q/D^{2.5} \) is less than 6.0, then

\[ L_{\text{max}} = 10D = 10(6) = 60 \text{ ft} \]

Therefore, use 60 feet for basin length.

Step 5: Determine the maximum riprap depth

From Figure 5-6, maximum depth = \( 2d_{50} = 2(2) = 4 \text{ ft} \)

5.7.3 Examples - Multiple Conduit Outlet Protection

Example 1 - Similar Pipes

Given: Triple 36 inch (3-foot) culvert at \( S_o = 0.010 \text{ ft/ft} \)

\[ n = 0.012 \]
FIGURE 5-2. GRADATION CURVES FOR GRANULAR BEDDING
NOTE: Always place fabric starting downstream and work upstream.

**FIGURE 5-3a. TYPICAL LAP DETAIL AND FILTER FABRIC PLACEMENT**

**FIGURE 5-3b. FILTER FABRIC AT RIPRAPH CHUTE DROP**

NOTE: Some soils may require a hydraulic cut off to prevent piping failure of drops.

**FIGURE 5-3c. FILTER FABRIC PLACEMENT VERTICAL DROP**
FIGURE 5-4a. TOE PROTECTION RIPRAP CHANNEL LINING

FIGURE 5-4b.

FIGURE 5-4c.

TOE PROTECTION WIRE ENCLOSED ROCK LINING

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**FIGURE 5-5a. SLOPE MATTRESS LINING**

Key counterfort 12" into bank

Gabion counterfort

Anchor stake, 2" minimum diameter, at least 4' into bank

Granular bedding

Rock toe protection up to annual high water line

Gabion matter

CORNER LACING AND STAKING DETAIL PLAN

PROTECTION FROM UNDERMINING IN CASE OF SCOUR

---

**FIGURE 5-5b. GABION LINING CONFIGURATIONS**

W.S. Major Flow

Annual W.S.

Toe Protection

Granular bedding or filter fabric

Annual W.S.

Toe Protection

Maximum Scour Depth

W.S. Major Flow

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Extend riprap to height of culvert or normal channel depth, whichever is smaller.

Riprap thickness on channel side slopes equal to 1:5d50.

4:1 or flatter preferred.
3:1 maximum.

End slope at 1:1.

Granular Bedding.

Concrete cradle/cut-off, or standard headwall.

2:4:50

L/2

L/2

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FIGURE 5-6. CONDUIT OUTLET EROSION PROTECTION
Use $D_a$ instead of $D$ whenever flow is supercritical in the barrel.

** Use Type L for a distance of 3D downstream.

**FIGURE 5-7. RIPRAP EROSION PROTECTION AT CIRCULAR CONDUIT OUTLET.**

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Use $H_0$ instead of $H$ whenever culvert has supercritical flow in the barrel.

**Use Type L for a distance of $3H$ downstream.**

**FIGURE 5-8. RIPRAP EROSION PROTECTION AT RECTANGULAR CONDUIT OUTLET.**
FIGURE 5-9. EXPANSION FACTOR FOR CIRCULAR CONDUITS
FIGURE 5-10. EXPANSION FACTOR FOR RECTANGULAR CONDUITS

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RIPRAP

FIGURE 5-11. EXAMPLE GRANULAR FILTER DESIGN

FILTER LAYER

SAND

CLAY

SILT

GRAIN SIZE (mm)

PERCENT FINER BY WEIGHT

100

0.1

0.02

0.01

0.001

0.0001

0.00001

FILTER LAYER

SANDY-SILT BED MATERIAL

UPPER LIMIT

LOWER LIMIT

FILTER LAYER

FILTER LAYER

SAND

CLAY

SILT

GRAIN SIZE (mm)

PERCENT FINER BY WEIGHT

100

0.1

0.02

0.01

0.001

0.0001

0.00001

0.000001

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