APPENDIX 6.6:

SCOUR ANALYSIS

Existing and Proposed NCHRP Abutment Scour Calculations for 25-Year Design Return Frequency

Existing and Proposed NCHRP Abutment Scour Calculations for 50-Year Check Return Frequency

25-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	4/9/2020
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	4/22/2020

NCHRP 24-20 Abutment Scour Calculations

25-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate total **abutment scour** experienced by the: **Existing Bridge Abutment**

Method:

Use NCHRP 24-20 Abutment Scour Approach found in HEC-18 and the HEC-RAS model to solve for total scour depth for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

If the projected length of embankment is 75% or greater than the width of the floodplain then live-bed scour caluclation is used. If the projected length of embankment is less than 75% of the floodplain width then clear-water scour caluclation is used.

Existing bridge abutment is adjacent to stream; Therefore, length of emankment and floodplain are equal.

Calculations:

Determine Scour Condition for Abutment

L =	67.0	Length of Embankment
B_f =	67.0	Width of Floodplain
L/B_f =	1.00	

L/Bf >= 0.75 **Live-Bed Scour**

Calculate Live-Bed Scour

$$y_c = y_1\left(\frac{q_{2c}}{q_1}\right)^{6/7}$$

y_1 =	3.76	Upstream flow depth, ft	River Section: 26.4
V =	3.18	Upstream Velocity, ft/s	
q_1 =	12.0	Upstream unit discharge, ft^2/s	
Q =	209.0	Total discharge in bridge opening, cfs	
W =	12.0	Width of Bridge Opening, ft	
q_{2c} =	17.4	Unit discharge in constricted opening accounting for non-uniform flow distribution, ft^2/s	
y_c =	5.2	Flow depth including live-bed contraction scour, ft	

25-YR

Project:	Bruce Freeman Rail Trail over Pantry Brook		
Job No.:	E2X81800	Location:	Sudbury, MA
Calced By:	AMS	Date:	4/9/2020
Checked By:	JRB	Date:	4/22/2020

(Type input values into the shaded boxes)

NCHRP 24-20 Abutment Scour Calculations

25-YR

$$y_{max} = \alpha_A y_c$$

$$y_s = y_{max} - y_0$$

q_{2c} / q_1 =	1.5	
α_A =	1.60	Amplication factor for live-bed conditions, from table
y_c =	5.2	Flow depth including live-bed contraction scour, ft
y_{max} =	8.3	Maximum flow depth resulting from abutment scour, ft
y_0 =	3.28	Bridge channel flow depth prior to scour, ft
y_s =	5.0	Abutment Scour Depth

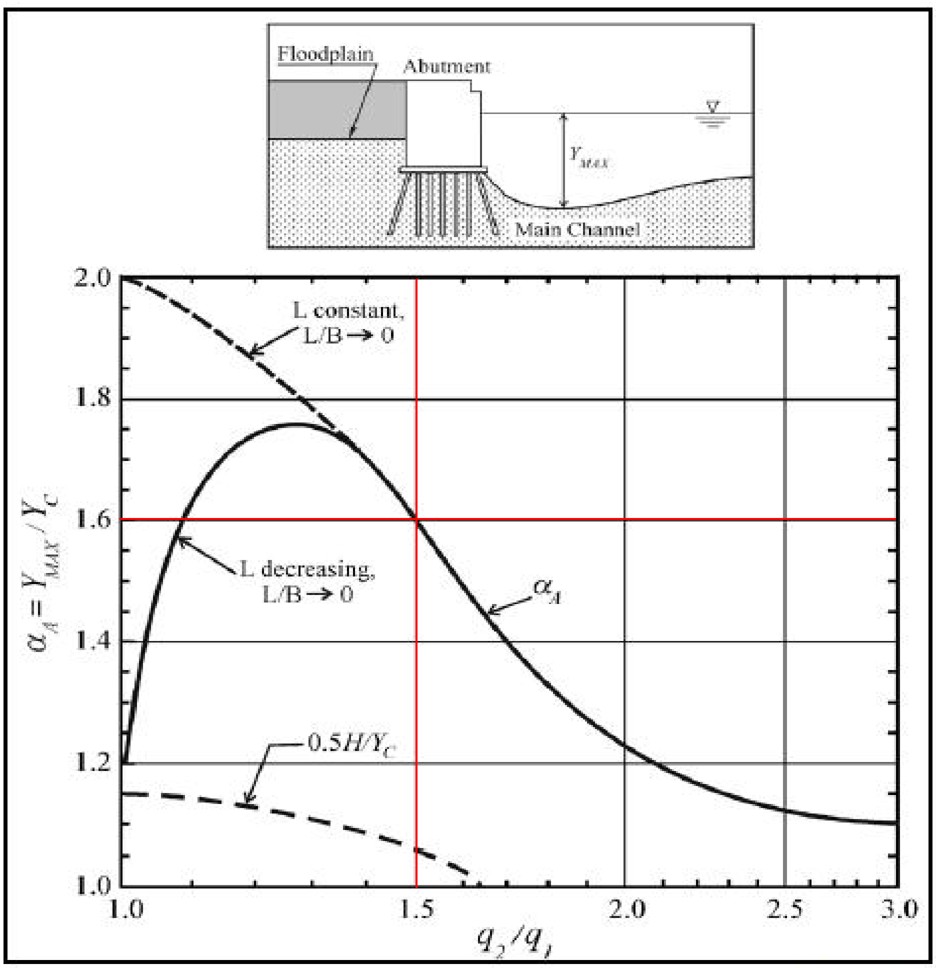

Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).

50-YR		Project:	Bruce Freeman Rail Trail over Pantry Brook		
		Job No.:	E2X81800	Location:	Sudbury, MA
		Calced By:	AMS	Date:	4/9/2020
(Type input values into the shaded boxes)		Checked By:	JRB	Date:	4/22/2020

NCHRP 24-20 Abutment Scour Calculations

50-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate total **abutment scour** experienced by the: **Existing Bridge Abutment**

Method:

Use NCHRP 24-20 Abutment Scour Approach found in HEC-18 and the HEC-RAS model to solve for total scour depth for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

If the projected length of embankment is 75% or greater than the width of the floodplain then live-bed scour caluclation is used. If the projected length of embankment is less than 75% of the floodplain width then clear-water scour caluclation is used.

Existing bridge abutment is adjacent to stream; Therefore, length of emankment and floodplain are equal.

Calculations:

Determine Scour Condition for Abutment

L =	67.0	Length of Embankment
B_f =	67.0	Width of Floodplain
L/B_f =	1.00	

L/Bf >= 0.75 **Live-Bed Scour**

Calculate Live-Bed Scour

$$y_c = y_1 \left(\frac{q_{2c}}{q_1}\right)^{6/7}$$

y_1 =	4.82	Upstream flow depth, ft
V =	2.97	Upstream Velocity, ft/s
q_1 =	14.3	Upstream unit discharge, ft^2/s
Q =	253.0	Total discharge in bridge opening, cfs
W =	12.0	Width of Bridge Opening, ft
q_{2c} =	21.1	Unit discharge in constricted opening accounting for non-uniform flow distribution, ft^2/s

River Section: 26.4

y_c =	6.7	Flow depth including live-bed contraction scour, ft

50-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	4/9/2020
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	4/22/2020

NCHRP 24-20 Abutment Scour Calculations

50-YR

$$y_{max} = \alpha_A y_c$$

$$y_s = y_{max} - y_0$$

q_{2c}/q_1 =	1.5	
α_A =	1.60	Amplication factor for live-bed conditions, from table
y_c =	6.7	Flow depth including live-bed contraction scour, ft
y_{max} =	10.7	Maximum flow depth resulting from abutment scour, ft
y_0 =	4.47	Bridge channel flow depth prior to scour, ft

y_s =	6.3	Abutment Scour Depth

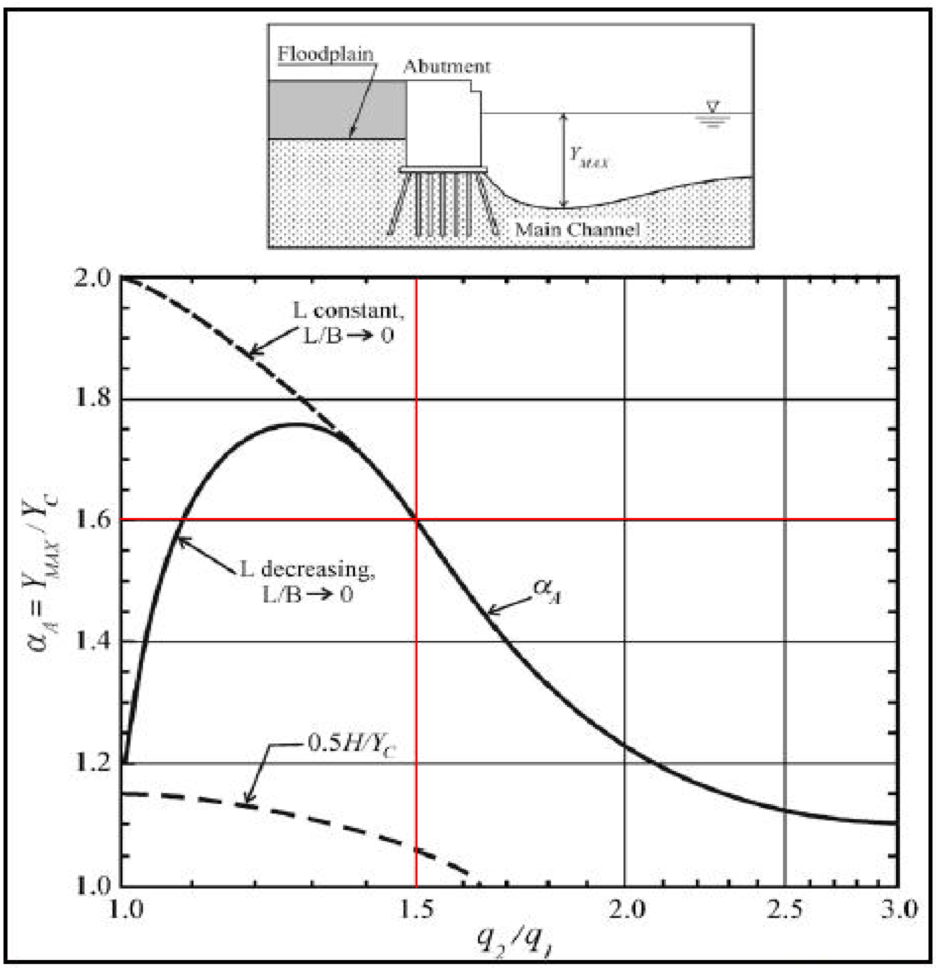

Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).

25-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	4/9/2020
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	4/22/2020

NCHRP 24-20 Abutment Scour Calculations

25-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate total **abutment scour** experienced by the: **Proposed Bridge Abutment**

Method:

Use NCHRP 24-20 Abutment Scour Approach found in HEC-18 and the HEC-RAS model to solve for total scour depth for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

If the projected length of embankment is 75% or greater than the width of the floodplain then live-bed scour caluclation is used. If the projected length of embankment is less than 75% of the floodplain width then clear-water scour caluclation is used.

Calculations:

Determine Scour Condition for Abutment

L =	60.7	Length of Embankment
B_f =	63.0	Width of Floodplain
L/B_f =	0.96	

L/Bf >= 0.75 **Live-Bed Scour**

Calculate Live-Bed Scour

$$y_c = y_1 \left(\frac{q_{2c}}{q_1}\right)^{6/7}$$

y_1 =	3.38	Upstream flow depth, ft	River Section: 26.4
V =	3.38	Upstream Velocity Total, ft/s	
q_1 =	11.4	Upstream unit discharge, ft^2/s	
Q =	209.0	Total discharge in bridge opening, cfs	
W =	24.66	Width of Bridge Opening, ft	
q_{2c} =	8.5	Unit discharge in constricted opening accounting for non-uniform flow distribution, ft^2/s	

y_c =	2.6	Flow depth including live-bed contraction scour, ft

25-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	4/9/2020
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	4/22/2020

NCHRP 24-20 Abutment Scour Calculations

25-YR

$$y_{max} = \alpha_A y_c$$

$$y_s = y_{max} - y_0$$

q_{2c} / q_1 =	0.7	
α_A =	1.20	Amplication factor for live-bed conditions, from table
y_c =	2.6	Flow depth including live-bed contraction scour, ft
y_{max} =	3.1	Maximum flow depth resulting from abutment scour, ft
y_0 =	2.58	Bridge channel flow depth prior to scour, ft
y_s =	0.6	Abutment Scour Depth

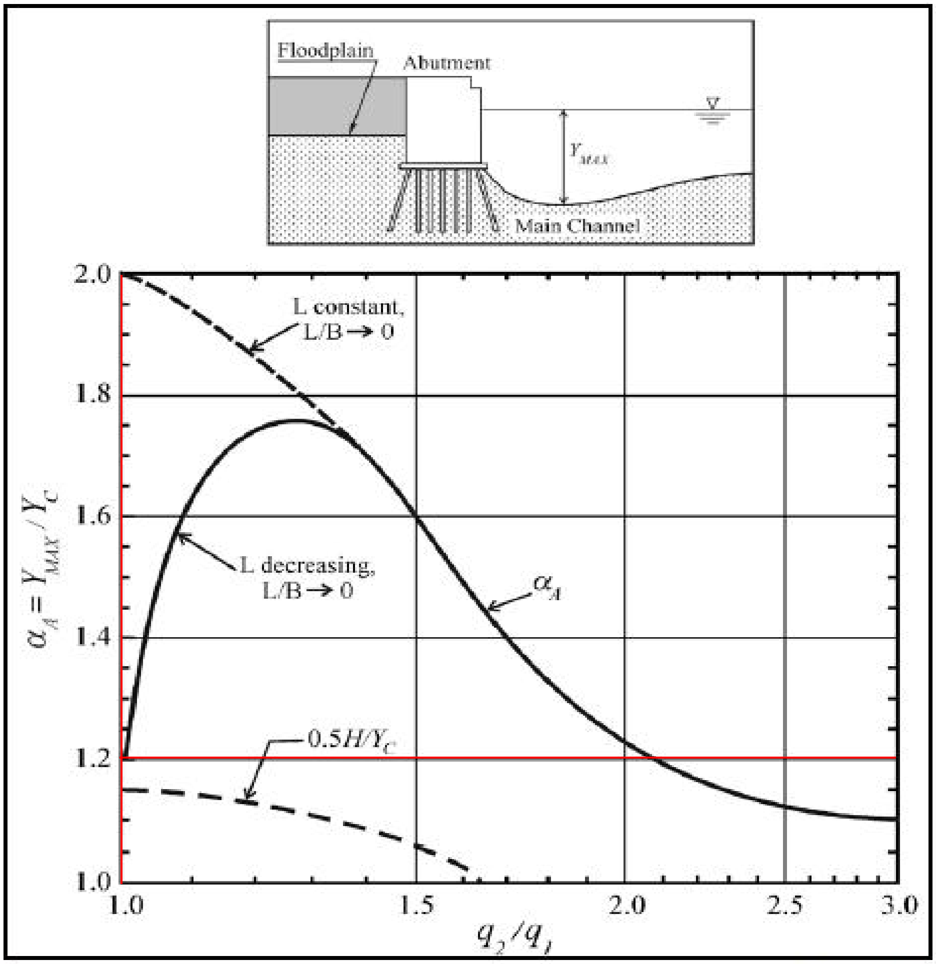

Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).

50-YR				
	Project:	Bruce Freeman Rail Trail over Pantry Brook		
	Job No.:	E2X81800	Location:	Sudbury, MA
	Calced By:	AMS	Date:	4/9/2020
(Type input values into the shaded boxes)	Checked By:	JRB	Date:	4/22/2020

NCHRP 24-20 Abutment Scour Calculations

50-YR

For Bruce Freeman Rail Trail Over Pantry Brook

Objective:

Calculate total **abutment scour** experienced by the: **Proposed Bridge Abutment**

Method:

Use NCHRP 24-20 Abutment Scour Approach found in HEC-18 and the HEC-RAS model to solve for total scour depth for the 25-year storm. See Chapter 8 of HEC-18.

Assumptions:

If the projected length of embankment is 75% or greater than the width of the floodplain then live-bed scour caluclation is used. If the projected length of embankment is less than 75% of the floodplain width then clear-water scour caluclation is used.

Calculations:

Determine Scour Condition for Abutment

L =	60.7	Length of Embankment
B_f =	63.0	Width of Floodplain
L/B_f =	0.96	

L/Bf >= 0.75 **Live-Bed Scour**

Calculate Live-Bed Scour

$$y_c = y_1 \left(\frac{q_{2c}}{q_1}\right)^{6/7}$$

y_1 =	4.55	Upstream flow depth, ft
V =	2.91	Upstream Velocity Total, ft/s
q_1 =	13.2	Upstream unit discharge, ft^2/s
Q =	253.0	Total discharge in bridge opening, cfs
W =	21.72	Width of Bridge Opening, ft
q_{2c} =	11.6	Unit discharge in constricted opening accounting for non-uniform flow distribution, ft^2/s

River Section: 26.4

y_c =	4.1	Flow depth including live-bed contraction scour, ft

50-YR

Project:	Bruce Freeman Rail Trail over Pantry Brook		
Job No.:	E2X81800	Location:	Sudbury, MA
Calced By:	AMS	Date:	4/9/2020
Checked By:	JRB	Date:	4/22/2020

(Type input values into the shaded boxes)

NCHRP 24-20 Abutment Scour Calculations

50-YR

$$y_{max} = \alpha_A y_c$$

$$y_s = y_{max} - y_0$$

q_{2c} / q_1 =	0.9	
α_A =	1.20	Amplication factor for live-bed conditions, from table
y_c =	4.1	Flow depth including live-bed contraction scour, ft
y_{max} =	4.9	Maximum flow depth resulting from abutment scour, ft
y_0 =	4.20	Bridge channel flow depth prior to scour, ft
y_s =	0.7	Abutment Scour Depth

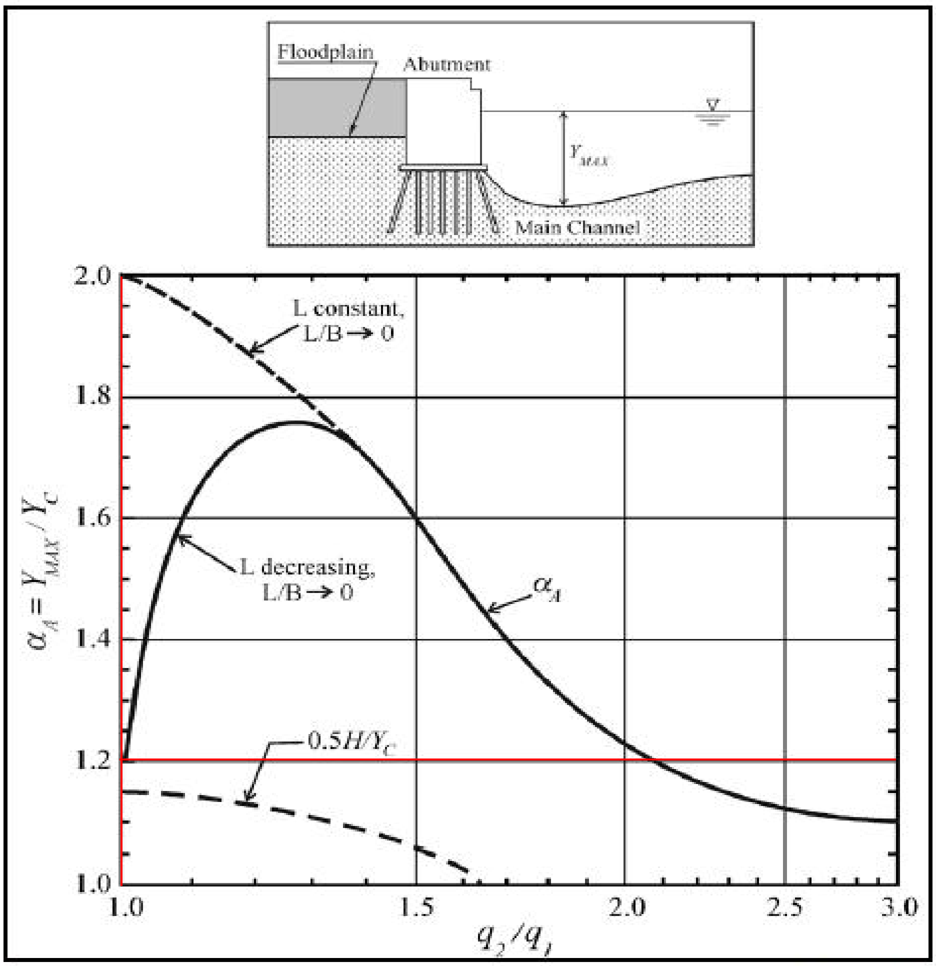

Figure 8.10. Scour amplification factor for wingwall abutments and live-bed conditions (NCHRP 2010b).

APPENDIX 6.7:

RIPRAP PROTECTION CALCULATIONS

JACOBS	
2 EXECUTIVE PARK DRIVE BEDFORD, NH 603-666-7181	JOB NO. E2X81800 - Bruce Freeman Rail Trail over Pantry Brook SHEET NO. 1 OF 1 CALCULATED BY: AMS DATE: 4/17/2020 CHECKED BY: JRB DATE: 4/22/2020

Objective

Use the Federal Highway Administration's HEC-23, Sizing Rock Rip-rap at Abutments, to calculate the size of rip-rap, d_{50}, at the existing abutment.

Method

Use results from the 50-year existing conditions HEC-RAS analysis to calculate the d_{50}.

V =	Average velocity in the contracted section	5.34	ft/sec	
y =	Depth of Flow in the Contracted Section	4.47	ft	
S_s =	Specific Gravity of Rock Rip-Rap	2.65		
g =	Gravitational Acceleration	32.2	ft/sec^2	
Froude Number =	$V/(gy)^{1/2}$	0.45	Subcritical	Use ≤ 0.80
K =	Constants for equations are different, see below.	1.02		
d_{50} =	Stone diameter	0.55	ft	
		6.57	in	

If Froude Number is ≤ 0.80:

$$d_{50} = \left(\frac{K}{(S_s - 1)}\left[\frac{V^2}{gy}\right]\right)y$$

K = Constant: 1.02 for Vertical Wall Abutment
0.89 for spill-through abutment

If Froude Number is > 0.80:

$$\frac{D_{50}}{y} = \frac{K}{(S_s - 1)}\left[\frac{V^2}{gy}\right]^{0.14}$$

K = Constant: 0.69 for Vertical Wall Abutment
0.61 for spill-through abutment

Results

Use d_{50}	6.57 in
Thickness (	9.86 in

=1.5 times d_{50}

Reference

Hydraulic Engineering Circular No. 23, Publication No. FHWA NHI 01-003, "Bridge Scour and Stream Instability Countermeasures," Second Edition, March 2001

Objective

Use the Federal Highway Administration's HEC-23, Sizing Rock Rip-rap at Abutments, to calculate the size of rip-rap, d_{50}, at the proposed abutment.

Method

Use results from the 50-year proposed conditions HEC-RAS analysis to calculate the d_{50}.

V = Average velocity in the contracted section	2.77	ft/sec	
y = Depth of Flow in the Contracted Section	4.2	ft	
S_s = Specific Gravity of Rock Rip-Rap	2.65		
g = Gravitational Acceleration	32.2	ft/sec^2	
Froude Number = $V/(gy)^{1/2}$	0.24	Subcritical	Use ≤ 0.80
K = Constants for equations are different, see below.	1.02		
d_{50} = Stone diameter	0.15	ft	
	1.77	in	

If Froude Number is ≤ 0.80:

$$d_{50} = \left(\frac{K}{(S_s - 1)} \left[\frac{V^2}{gy} \right] \right) y$$

K = Constant: 1.02 for Vertical Wall Abutment
0.89 for spill-through abutment

If Froude Number is > 0.80:

$$\frac{D_{50}}{y} = \frac{K}{(S_s - 1)} \left[\frac{V^2}{gy} \right]^{0.14}$$

K = Constant: 0.69 for Vertical Wall Abutment
0.61 for spill-through abutment

Results

Use d_{50}	1.77 in
Thickness (	2.66 in

=1.5 times d_{50}

Reference

Hydraulic Engineering Circular No. 23, Publication No. FHWA NHI 01-003, "Bridge Scour and Stream Instability Countermeasures," Second Edition, March 2001