9 Appendices

Appendix A. FEMA's FIRM for the Project Area

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0 North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study Report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study Report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study Report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Massachusetts State Plane Mainland Zone (FIPS zone 2001). The **horizontal datum** was NAD 83, GRS 1980 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the same **vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713- 3242**, or visit its website at http://www.ngs.noaa.gov.

Base map information shown on this FIRM was derived from digital orthophotography. Base map files were provided in digital form by Massachusetts Geographic Information Systems (MassGIS). Ortho imagery was produced at a scale of 1:5,000. Aerial photoraphy is dated April 2005

The **profile baselines** depicted on this map represent the hydraulic modeling baselines that match the flood profiles in the FIS report. As a result of improved topographic data, the **profile baseline**, in some cases, may deviate significantly from the channel centerline or appear outside the SFHA.

Based on updated topographic information, this map reflects more detailed and up-to-date **stream channel configurations and floodplain delineations** than those shown on the previous FIRM for this jurisdiction. As a result, the Flood Profiles and Floodway Data tables for multiple streams in the Flood Insurance Study Report (which contains authoritative hydraulic data) may reflect stream channel distances that differ from what is shown on the map. Also, the road to floodplain relationships for unrevised streams may differ from what is shown on previous maps.

Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

For information on available products associated with this FIRM visit the **Map Service Center (MSC)** website at http://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the MSC website.

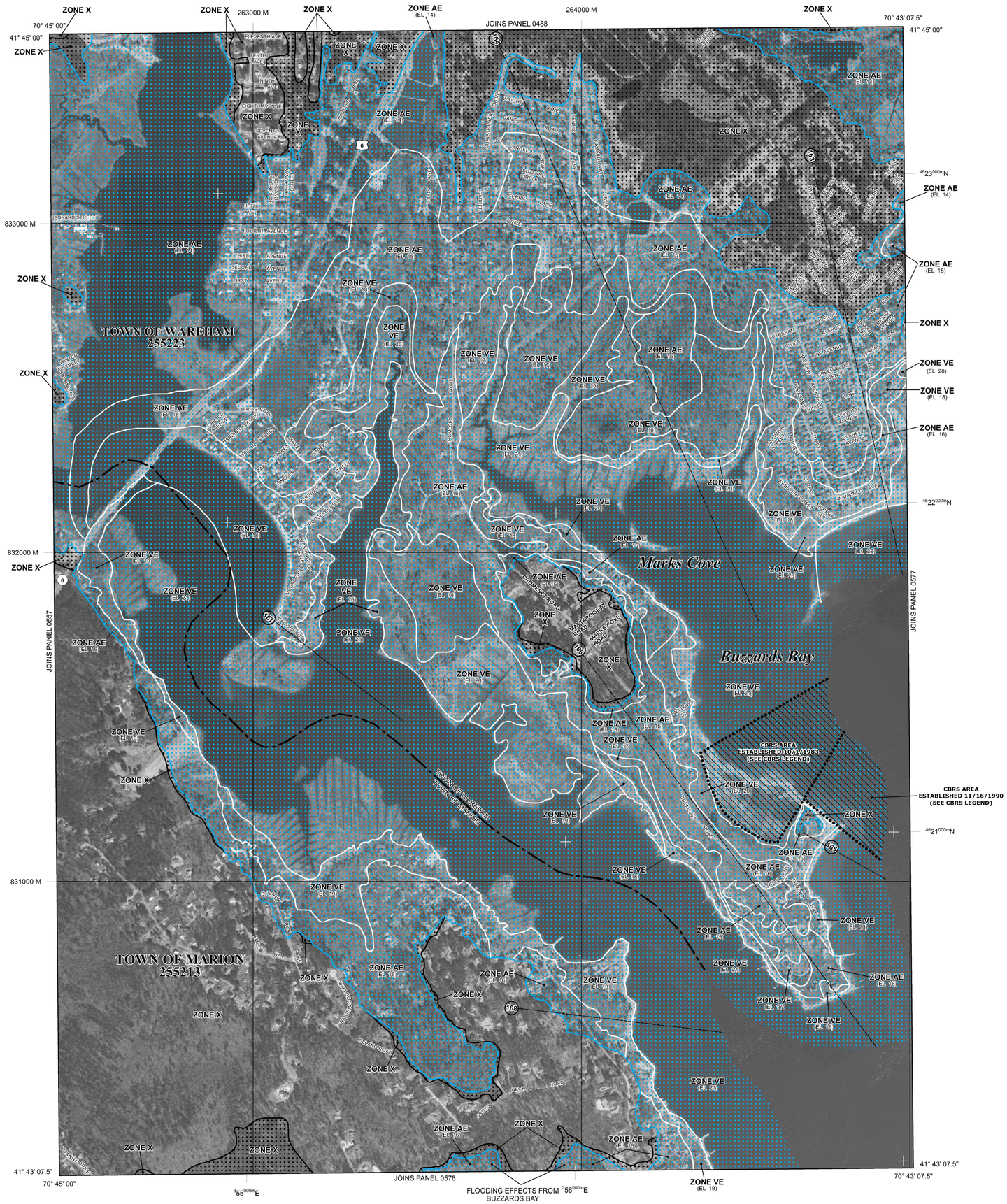
If you have **questions about this map,** how to order products, or the National Flood Insurance Program in general, please call the **FEMA Map Information eXchange (FMIX)** at **1-877-FEMA-MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov/business/nfip.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) LEGEND

11-16-1990 CBRS Area
FLOOD INSURANCE NOT AVAILABLE FOR STRUCTURES NEWLY BUILT OR SUBSTANTIALLY IMPROVED ON OR AFTER NOVEMBER 16, 1990 IN DESIGNATED CBRS AREAS.

10-01-1983 CBRS Area
FLOOD INSURANCE NOT AVAILABLE FOR STRUCTURES NEWLY BUILT OR SUBSTANTIALLY IMPROVED ON OR AFTER OCTOBER 01, 1983 IN DESIGNATED CBRS AREAS.

Boundaries of the John H. Chafee Coastal Barrier Resources System (CBRS) shown on this FIRM were transferred from the official CBRS source map(s) for this area and are depicted on this FIRM for informational purposes only. The official CBRS maps are enacted by Congress via the Coastal Barrier Resources Act, as amended, and maintained by the U.S. Fish and Wildlife Service (FWS). The official CBRS maps used to determine whether or not an area is located within the CBRS are available for download at http://www.fws.gov. For an official determination of whether or not an area is located within the CBRS, or for any questions regarding the CBRS, please contact the FWS field office for this area at 603-223-2541.



LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

The 1% annual chance flood (100-year flood), also known as the base flood, is the flood that has a 1% chance of being equaled or exceeded in any given year. The Special Flood Hazard Area is the area subject to flooding by the 1% annual chance flood. Areas of Special Flood Hazard include Zones A, AE, AH, AO, AR, A99, V, and VE. The Base Flood Elevation is the water-surface elevation of the 1% annual chance flood.

ZONE A	No Base Flood Elevations determined.
ZONE AE	Base Flood Elevations determined.
ZONE AH	Flood depths of 1 to 3 feet (usually areas of ponding); Base Flood Elevations determined.
ZONE AO	Flood depths of 1 to 3 feet (usually sheet flow on sloping terrain); average depths determined. For areas of alluvial fan flooding, velocities also determined.
ZONE AR	Special Flood Hazard Areas formerly protected from the 1% annual chance flood by a flood control system that was subsequently decertified. Zone AR indicates that the former flood control system is being restored to provide protection from the 1% annual chance or greater flood.
ZONE A99	Area to be protected from 1% annual chance flood by a Federal flood protection system under construction; no Base Flood Elevations determined.
ZONE V	Coastal flood zone with velocity hazard (wave action); no Base Flood Elevations determined.
ZONE VE	Coastal flood zone with velocity hazard (wave action); Base Flood Elevations determined.

FLOODWAY AREAS IN ZONE AE

The floodway is the channel of a stream plus any adjacent floodplain areas that must be kept free of encroachment so that the 1% annual chance flood can be carried without substantial increases in flood heights.

OTHER FLOOD AREAS

ZONE X	Areas of 0.2% annual chance flood; areas of 1% annual chance flood with average depths of less than 1 foot or with drainage areas less than 1 square mile; and areas protected by levees from 1% annual chance flood.

OTHER AREAS

ZONE X	Areas determined to be outside the 0.2% annual chance floodplain.
ZONE D	Areas in which flood hazards are undetermined, but possible.

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

CBRS areas and OPAs are normally located within or adjacent to Special Flood Hazard Areas.

1% Annual Chance Floodplain Boundary

0.2% Annual Chance Floodplain Boundary

Floodway boundary

Zone D boundary

CBRS and OPA boundary

Boundary dividing Special Flood Hazard Area Zones and boundary dividing Special Flood Hazard Areas of different Base Flood Elevations, flood depths, or flood velocities.

513	Base Flood Elevation line and value; elevation in feet*
(EL 987)	Base Flood Elevation value where uniform within zone; elevation in feet*

*Referenced to the North American Vertical Datum of 1988

A — A	Cross section line
23 - - - - 23	Transect line
	Culvert
	Bridge
45° 02' 08", 93° 02' 12"	Geographic coordinates referenced to the North American Datum of 1983 (NAD 83) Western Hemisphere
4989000 M	1000-meter ticks: Massachusetts State Plane Mainland Zone (FIPS Zone 2001), Lambert Conformal Conic projection
$^{49}89^{000m}$ N	1000-meter Universal Transverse Mercator grid values, zone 19N
DX5510 ×	Bench mark (see explanation in Notes to Users section of this FIRM panel)
• M1.5	River Mile

MAP REPOSITORIES
Refer to Map Repositories list on Map Index

EFFECTIVE DATE OF COUNTYWIDE
FLOOD INSURANCE RATE MAP
July 17, 2012

EFFECTIVE DATE(S) OF REVISION(S) TO THIS PANEL
February 5, 2014 - to change Special Flood Hazard Areas.

For community map revision history prior to countywide mapping, refer to the Community Map History table located in the Flood Insurance Study report for this jurisdiction.

To determine if flood insurance is available in this community, contact your insurance agent or call the National Flood Insurance Program at 1-800-638-6620.

MAP SCALE 1" = 500'

250 0 500 1000 FEET

150 0 150 300 METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0576K

FIRM

FLOOD INSURANCE RATE MAP

PLYMOUTH COUNTY, MASSACHUSETTS (ALL JURISDICTIONS)

PANEL 576 OF 650

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

COMMUNITY	NUMBER	PANEL	SUFFIX
MARION, TOWN OF	255213	0576	K
WAREHAM, TOWN OF	255223	0576	K

-NOTE-
THIS MAP INCLUDES BOUNDARIES OF THE COASTAL BARRIER RESOURCES SYSTEM ESTABLISHED UNDER THE COASTAL BARRIER RESOURCES ACT OF 1982 AND/OR SUBSEQUENT ENABLING LEGISLATION.

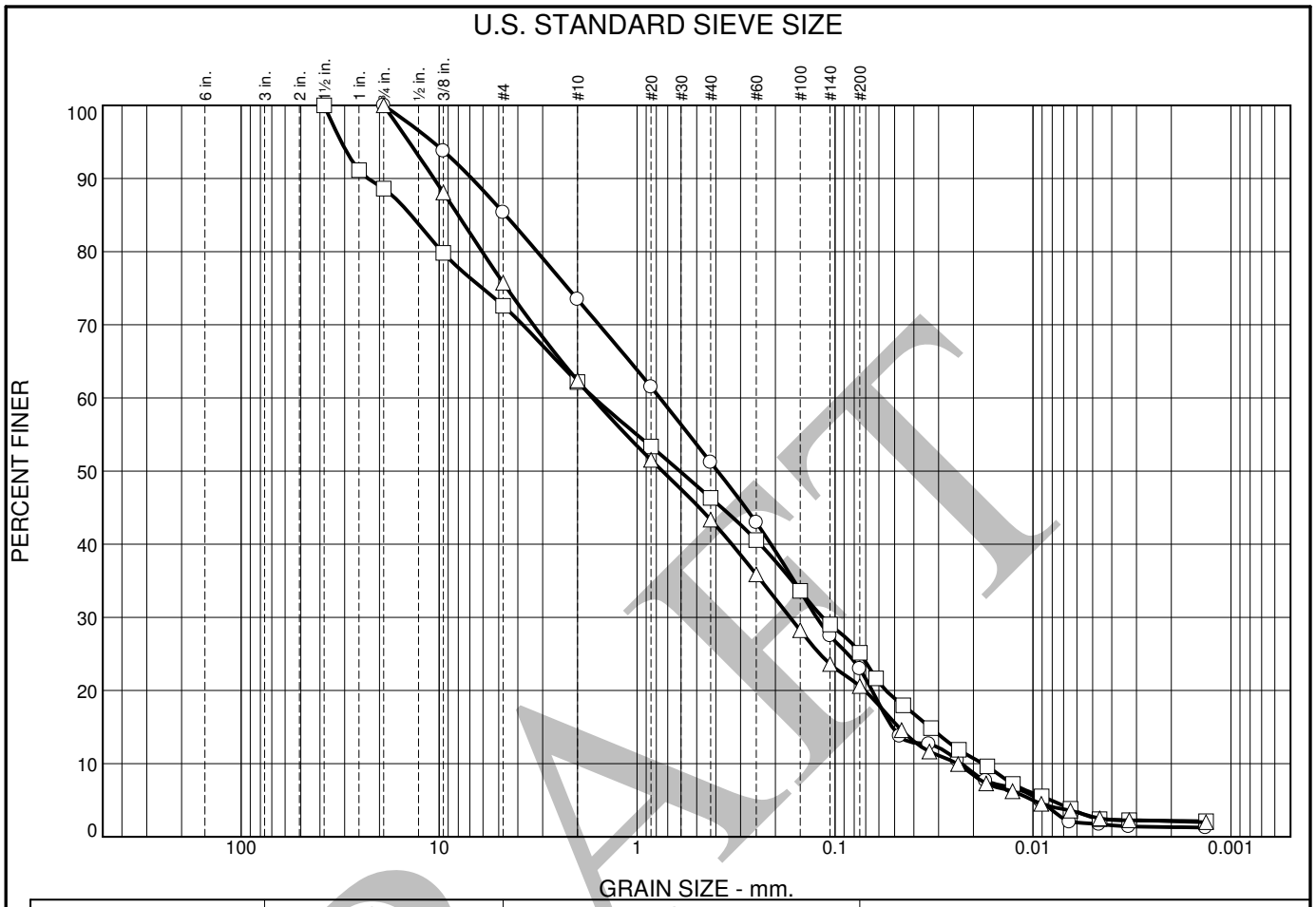
Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
25023C0576K

MAP REVISED
FEBRUARY 5, 2014

Federal Emergency Management Agency

Appendix B. Sediment Sampling



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	14.6	11.9	22.3	28.2	21.7	1.3
□	0.0	11.4	16.0	10.4	15.9	21.1	23.0	2.2
△	0.0	0.0	24.3	13.3	19.1	22.7	18.5	2.1

	Expl. No.	Sample No.	Depth (m.)	Atterberg Limits %			Water Content (%)	C_u	C_c	USCS
				W_L	W_P	I_P				
○	BB-3	S01	0.0-2.0 ft.				13.1	33.47	0.87	SM
□	BB-3	S03	4.0-6.0 ft.				12.0	91.83	0.45	SM
△	BB-3	S05	8.0-10.0 ft.				7.0	69.57	0.70	SM

	Sample Description
○	Gray brown silty sand
□	Red yellow silty sand with gravel
△	Red yellow silty sand with gravel

Remarks:

Bridge No. M-05-001 = W-06-013
Marion and Wareham, Massachusetts

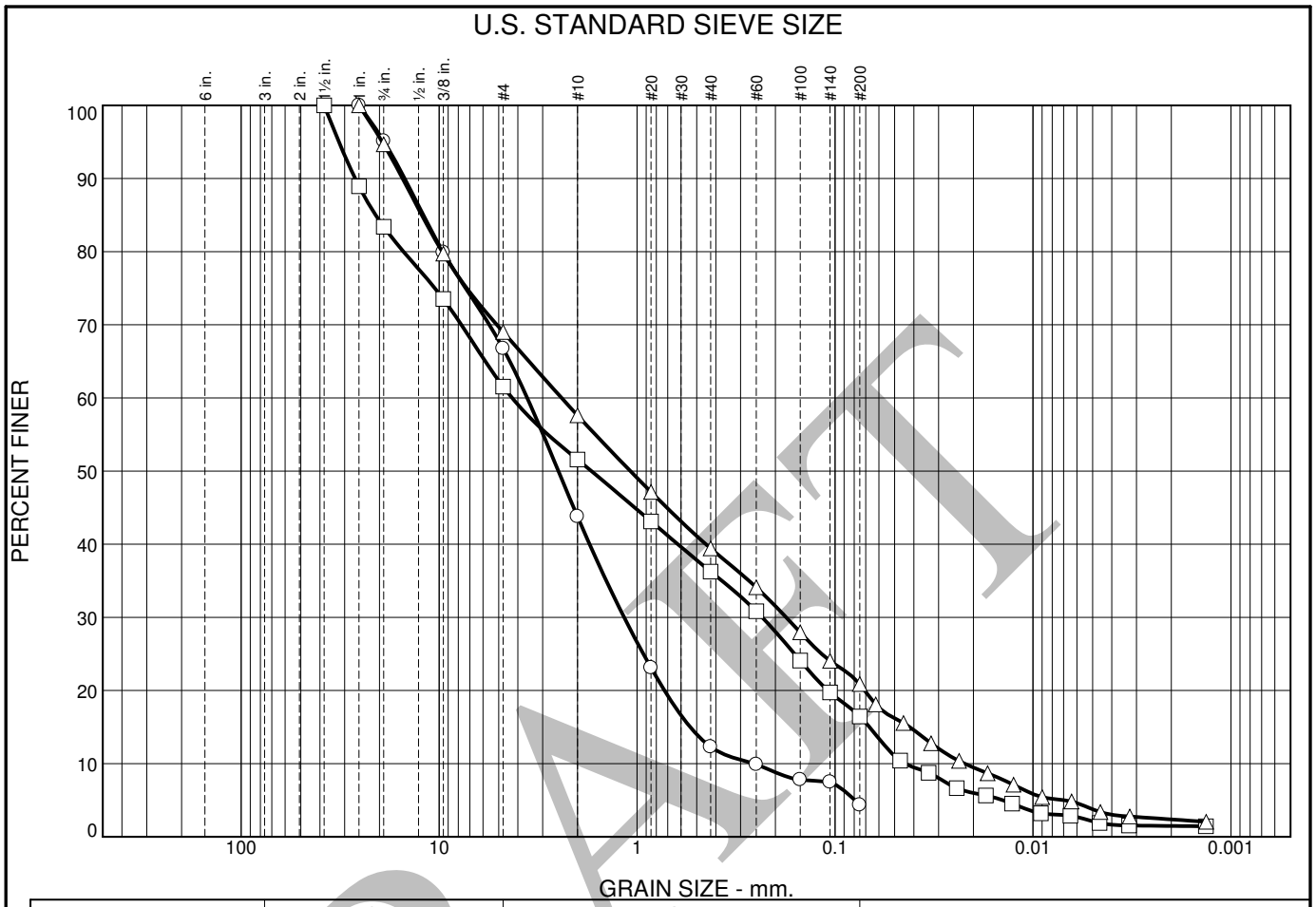
HALEY ALDRICH

GRAIN SIZE DISTRIBUTION

DATE: 5/9/2018

FILE NO: 40991-005

DRAFT



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	4.9	28.3	23.0	31.5	8.0	4.3	
□	0.0	16.6	21.9	9.9	15.3	19.8	15.0	1.5
△	0.0	5.3	25.7	11.4	18.2	18.5	18.5	2.4

	Expl. No.	Sample No.	Depth (m.)	Atterberg Limits %			Water Content (%)	C_u	C_c	USCS
				W_L	W_P	I_P				
○	BB-4	S01	0.0-2.0 ft.				18.5	13.96	1.46	SW
□	BB-4	S03	4.0-6.0 ft.				9.7	96.55	0.29	SM
△	BB-4	S06	10.0-11.7 ft.				12.4	108.62	0.59	SM

	Sample Description
○	Dark gray well-graded sand with gravel
□	Yellow silty sand with gravel
△	Tan silty sand with gravel

Remarks:

HALEY ALDRICH

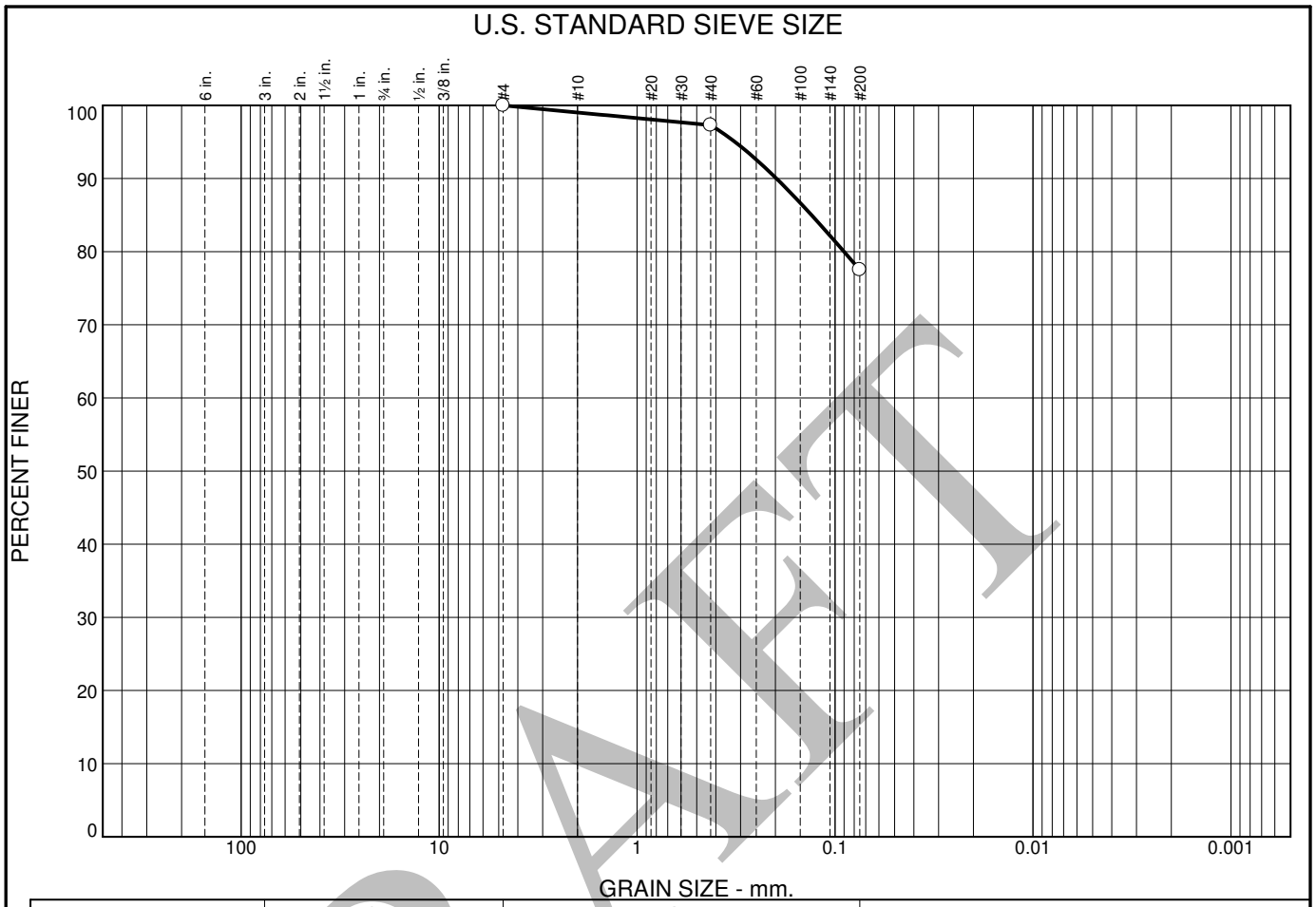
Bridge No. M-05-001 = W-06-013
Marion and Wareham, Massachusetts

GRAIN SIZE DISTRIBUTION

DATE: 5/9/2018

FILE NO: 40991-005

DRAFT



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	1.0	1.7	19.8	77.5	

	Expl. No.	Sample No.	Depth (m.)	Atterberg Limits %			Water Content (%)	C_u	C_c	USCS
				W_L	W_P	I_P				
○	BB-6	S07	29.0-31.0 ft.				53.3			

	Sample Description
○	Dark brown organic silt with sand

Remarks:

○Organic Content = 3.1%

HALEY ALDRICH

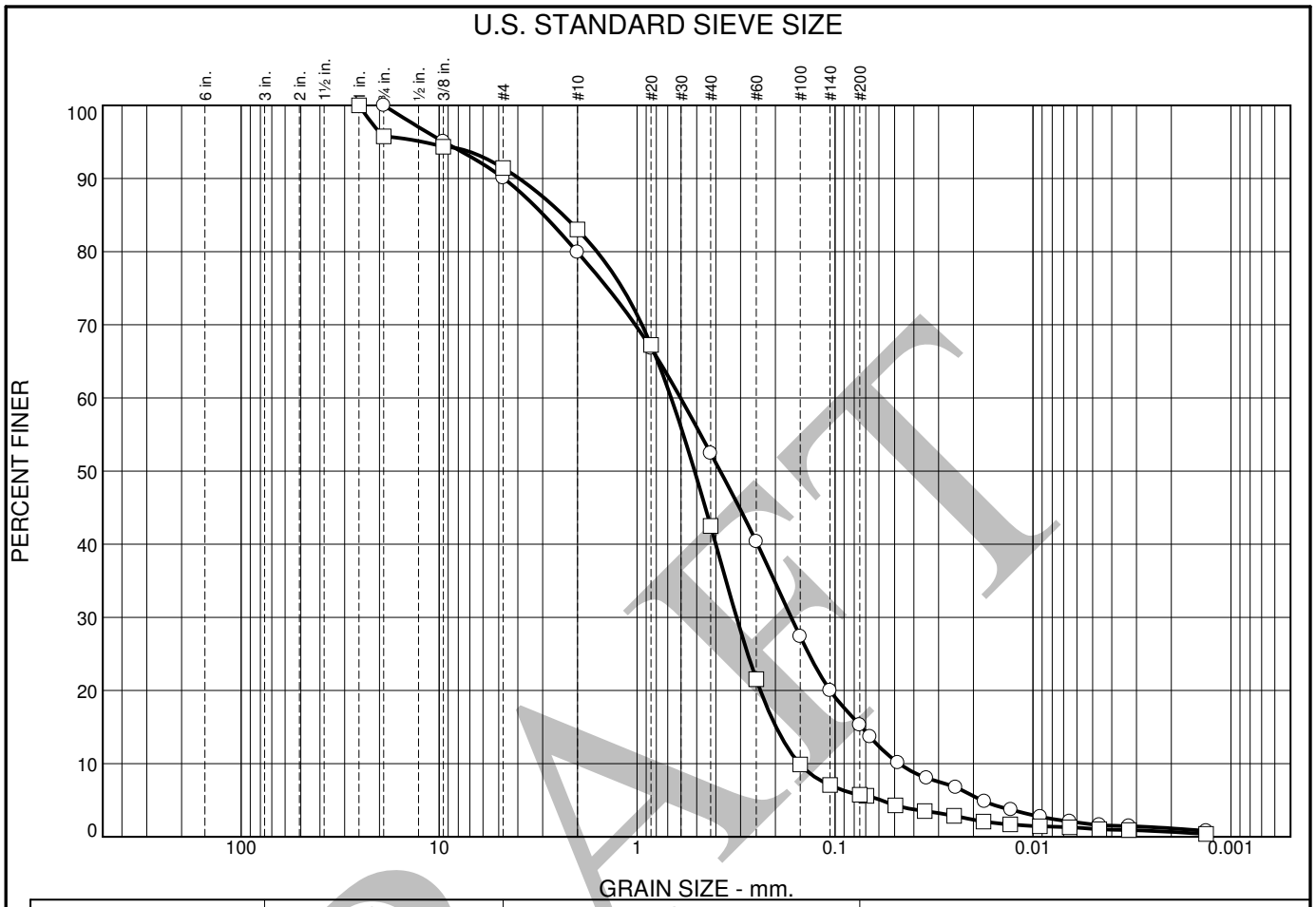
Bridge No. M-05-001 = W-06-013
Marion and Wareham, Massachusetts

GRAIN SIZE DISTRIBUTION

DATE: 5/9/2018

FILE NO: 40991-005

DRAFT



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	9.9	10.2	27.5	37.1	14.1	1.2
□	0.0	4.2	4.4	8.4	40.5	36.7	5.1	0.7

	Expl. No.	Sample No.	Depth (m.)	Atterberg Limits %			Water Content (%)	C_u	C_c	USCS
				W_L	W_P	I_P				
○	SS1		3.0-9.0 Inches				13.1	12.73	0.97	SM
□	SS2		3.0-9.0 inches				20.6	4.45	0.97	SP-SM

	Sample Description
○	Brown silty sand
□	Dark brown poorly graded sand with silt

Remarks:

HALEY ALDRICH

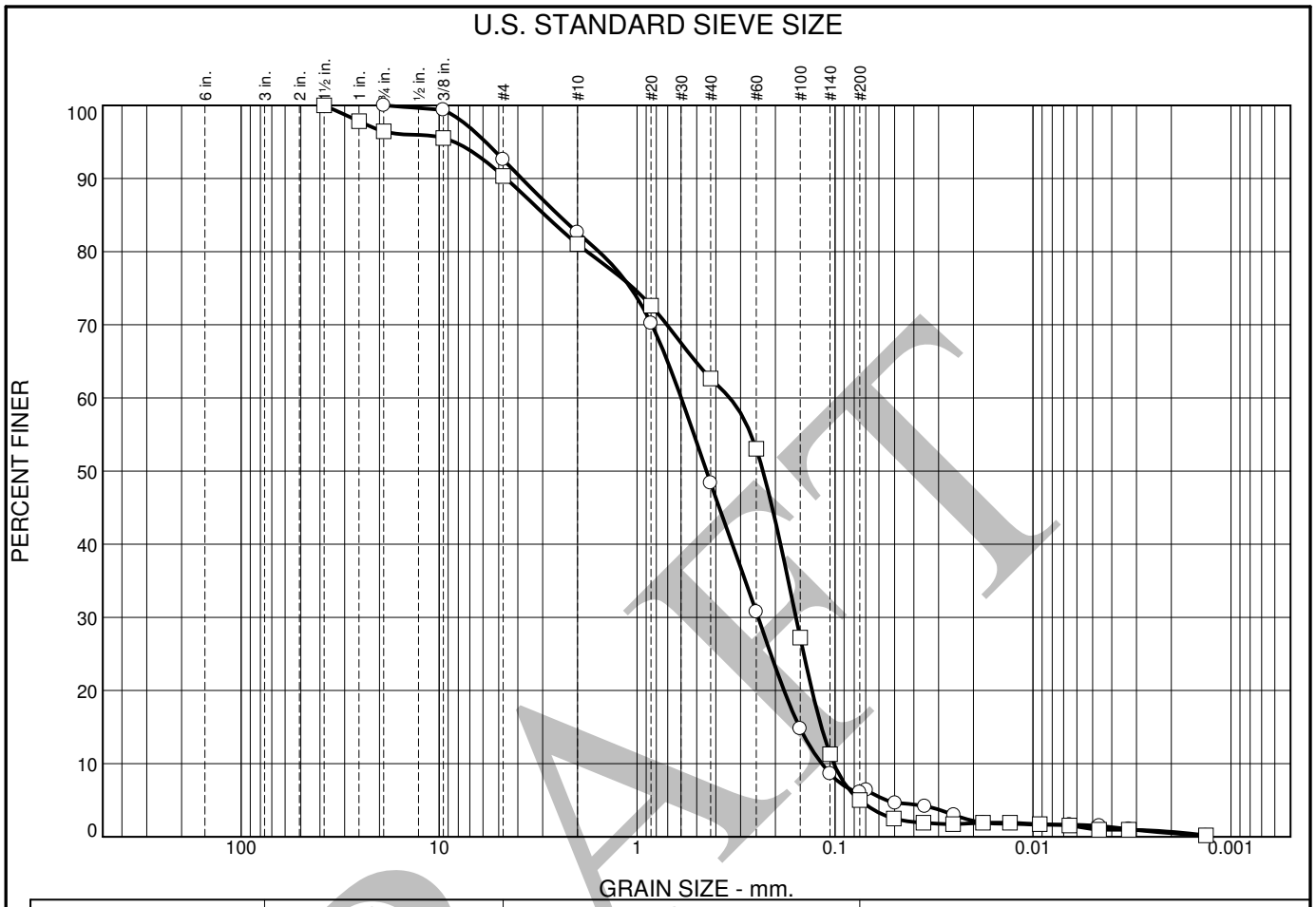
Bridge Nos. M-05-013 = W-06-013 and W-06-016
Marion and Wareham, Massachusetts

GRAIN SIZE DISTRIBUTION

DATE: 6/19/2018

FILE NO: 40991-005

DRAFT



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	7.4	10.0	34.2	42.3	5.6	0.5
□	0.0	3.6	6.1	9.3	18.3	57.7	4.3	0.7

	Expl. No.	Sample No.	Depth (m.)	Atterberg Limits %			Water Content (%)	C_u	C_c	USCS
				W_L	W_P	I_P				
○	Marion	Overbank	0.0-12.0 inches				23.8	5.13	0.86	SP-SM
□	Wareham	Overbank	0.0-12.0 inches				21.0	3.35	0.72	SP-SM

	Sample Description
○	Dark brown poorly graded sand with silt
□	Brown poorly graded sand with silt

Remarks:

HALEY ALDRICH

Bridge Nos. M-05-013 = W-06-013 and W-06-016
Marion and Wareham, Massachusetts

GRAIN SIZE DISTRIBUTION

DATE: 6/19/2018

FILE NO: 40991-005

DRAFT

TEST DATE: 4/23/2018

ORGANIC CONTENT RESULTS

FILE No.:	**40991-005**
PROJECT:	**Bridge No. M-05-001 = W-06-013** **Marion and Wareham, Massachusetts**

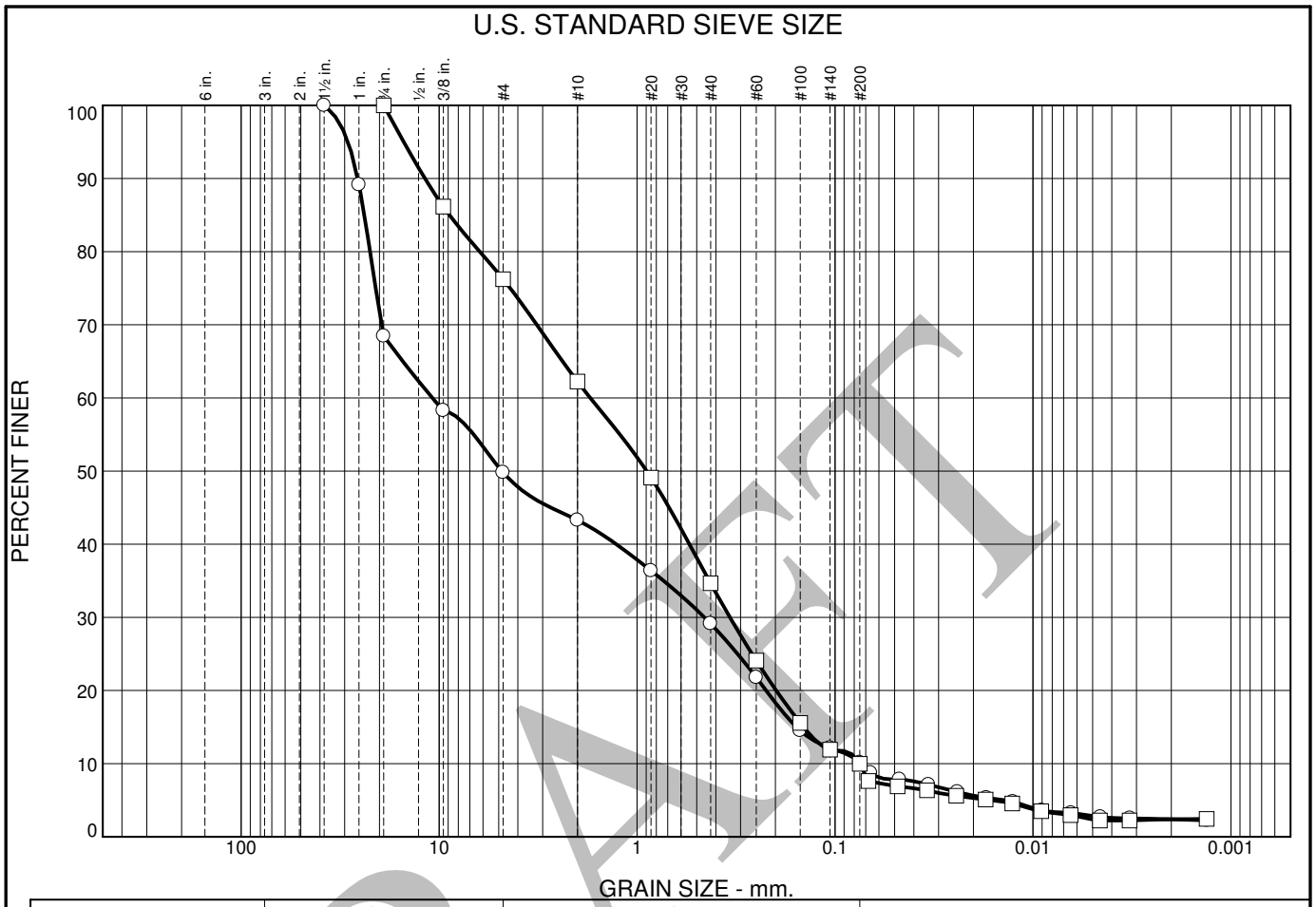
EXPL. No.:	BB-6
SAMPLE No.:	S07
DEPTH (ft.):	29.0-31.0
SAMPLE DESCRIPTION:	Dark brown organic silt with sand

"AS RECEIVED" WATER CONTENT

WT CONT. + WET SAMPLE (g)	124.74
WT CONT. + DRY SAMPLE (g)	87.51
WT CONTAINER (g)	15.87
MOISTURE CONTENT (%)	**52.0**

LOSS ON IGNITION

WT CONTAINERS + OVEN DRY SAMPLE BEFORE COMBUSTION (g)	44.2752
WT CONTAINERS + OVEN DRY SAMPLE AFTER COMBUSTION (g)	43.8745
WT CONTAINER (CRUCIBLE + B CAN)	31.4815
ORGANIC CONTENT (%)	**3.1**



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	31.5	18.7	6.5	14.2	18.9	7.8	2.4
□	0.0	0.0	23.8	14.0	27.5	24.7	7.6	2.4

	Expl. No.	Sample No.	Depth (m.)	Atterberg Limits %			Water Content (%)	C_u	C_c	USCS
				W_L	W_P	I_P				
○	BB-9	S01	0.0-2.0 ft.				65.5	146.20	0.26	GP-GM
□	BB-9	S03	4.5-6.5 ft.				31.2	22.95	0.89	SP-SM

	Sample Description
○	Light brown poorly graded gravel with silt and sand
□	Dark gray poorly graded sand with silt and gravel

Remarks:

HALEY ALDRICH

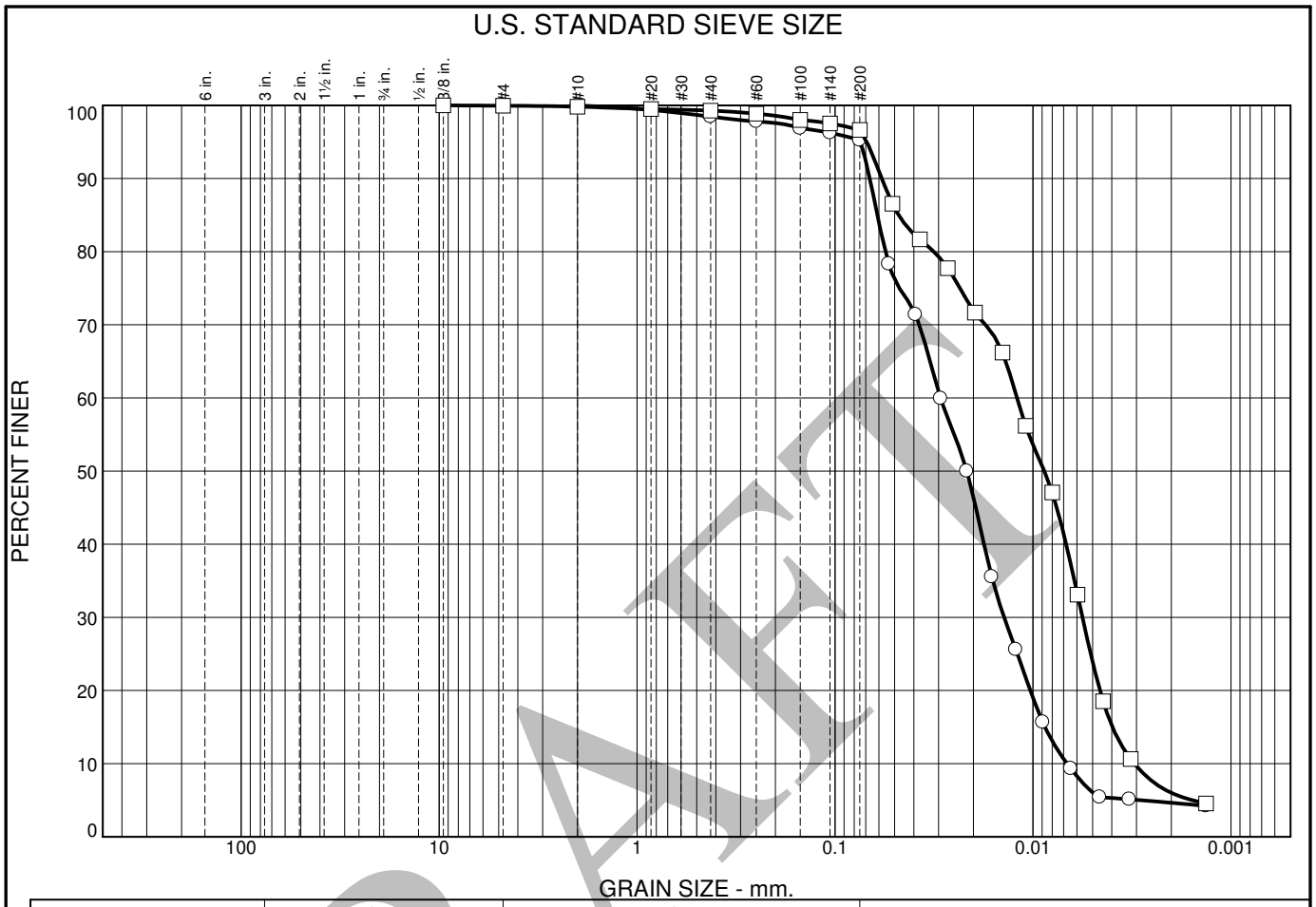
Bridge No. W-06-016
Wareham, Massachusetts

GRAIN SIZE DISTRIBUTION

DATE: 5/9/2018

FILE NO: 40991-005

DRAFT



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	0.0	0.0	1.5	3.2	90.7	4.6
□	0.0	0.0	0.0	0.2	0.5	2.7	90.6	6.0

	Expl. No.	Sample No.	Depth (m.)	Atterberg Limits %			Water Content (%)	C_u	C_c	USCS
				W_L	W_P	I_P				
○	BB-9	S04	6.5-8.5 ft.				32.3	4.36	0.99	ML
□	BB-9	S07	12.5-14.5 ft.				29.7	3.91	0.85	ML

	Sample Description
○	Olive gray silt
□	Light brown silt

Remarks:

HALEY ALDRICH

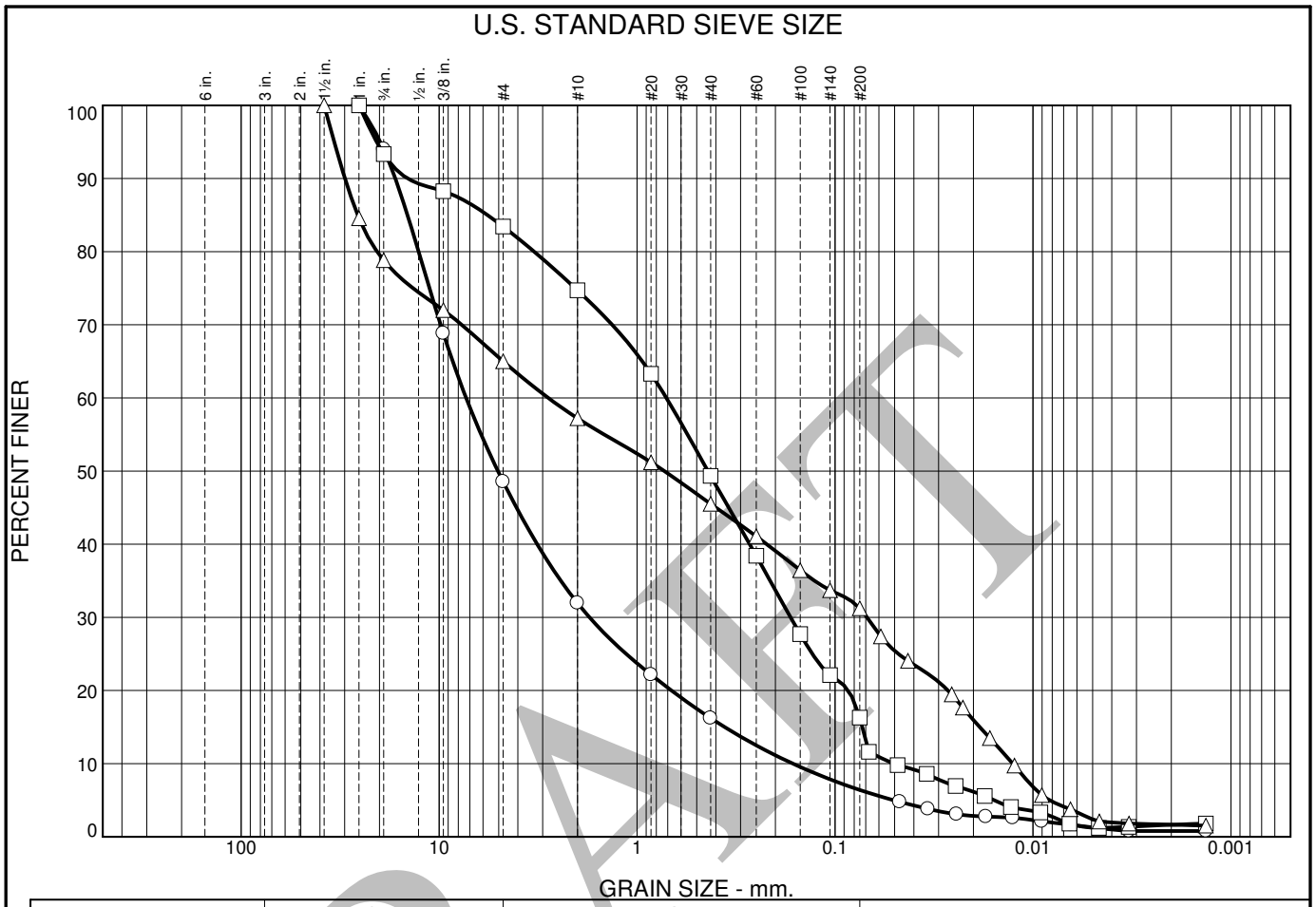
Bridge No. W-06-016
Wareham, Massachusetts

GRAIN SIZE DISTRIBUTION

DATE: 5/9/2018

FILE NO: 40991-005

DRAFT



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	6.0	45.4	16.6	15.8	9.8	5.6	0.8
□	0.0	6.7	9.9	8.7	25.4	33.0	14.7	1.6
△	0.0	21.2	13.8	7.8	11.7	14.3	29.5	1.7

	Expl. No.	Sample No.	Depth (m.)	Atterberg Limits %			Water Content (%)	C_u	C_c	USCS
				W_L	W_P	I_P				
○	BB-10	S01	0.0-2.0 ft.				41.4	44.75	2.53	GW-GM
□	BB-10	S03	4.0-6.0 ft.				13.9	14.12	0.79	SM
△	BB-10	S05	8.0-10.0 ft.		NP		12.2	222.08	0.13	GM

	Sample Description
○	Dark gray well-graded gravel with silt and sand
□	Brown silty sand with gravel
△	Olive silty gravel with sand

Remarks:

HALEY ALDRICH

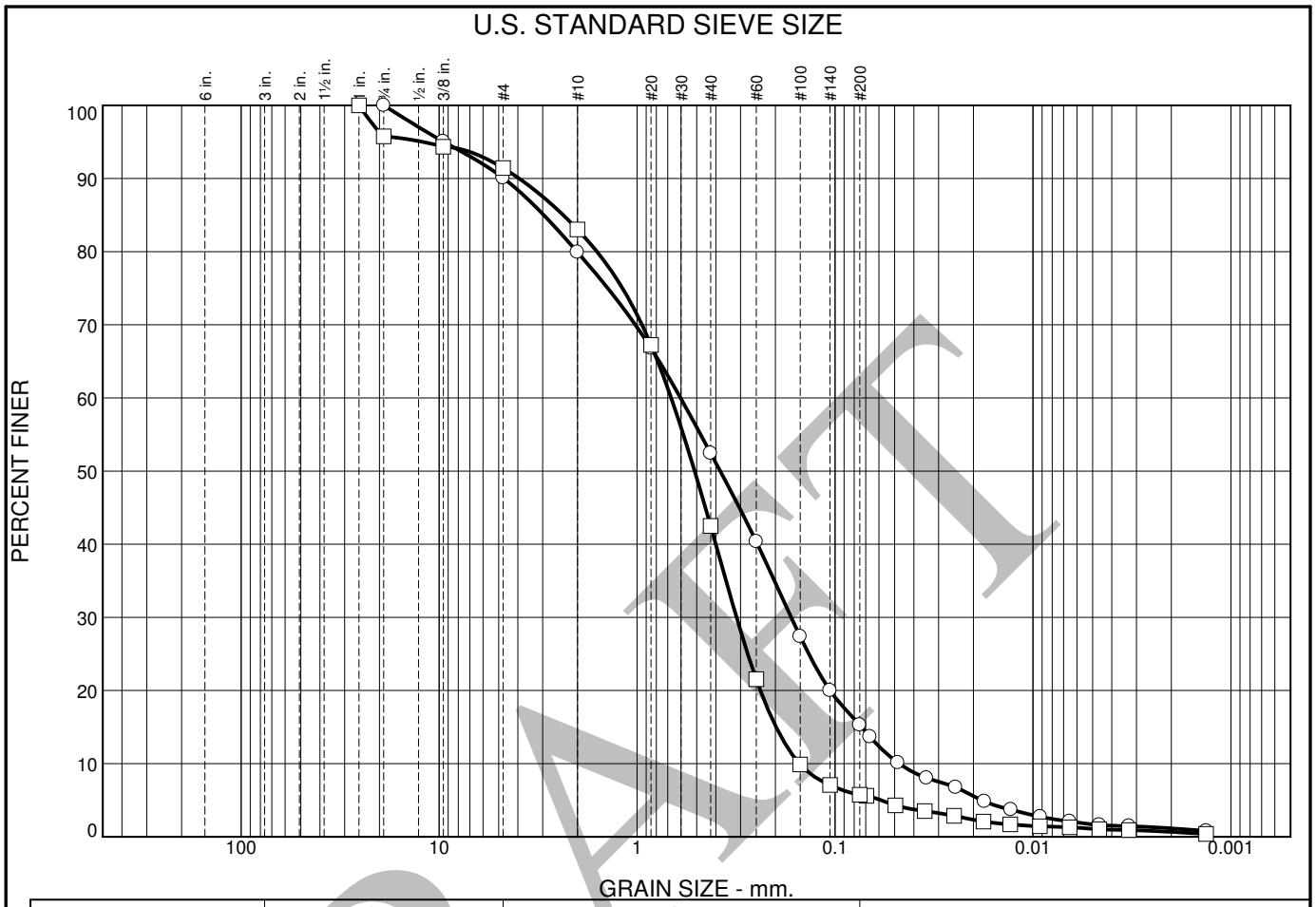
Bridge No. W-06-016
Wareham, Massachusetts

GRAIN SIZE DISTRIBUTION

DATE: 5/9/2018

FILE NO: 40991-005

DRAFT



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	9.9	10.2	27.5	37.1	14.1	1.2
□	0.0	4.2	4.4	8.4	40.5	36.7	5.1	0.7

	Expl. No.	Sample No.	Depth (m.)	Atterberg Limits %			Water Content (%)	C_u	C_c	USCS
				W_L	W_P	I_P				
○	SS1		3.0-9.0 Inches				13.1	12.73	0.97	SM
□	SS2		3.0-9.0 inches				20.6	4.45	0.97	SP-SM

	Sample Description
○	Brown silty sand
□	Dark brown poorly graded sand with silt

Remarks:

HALEY ALDRICH

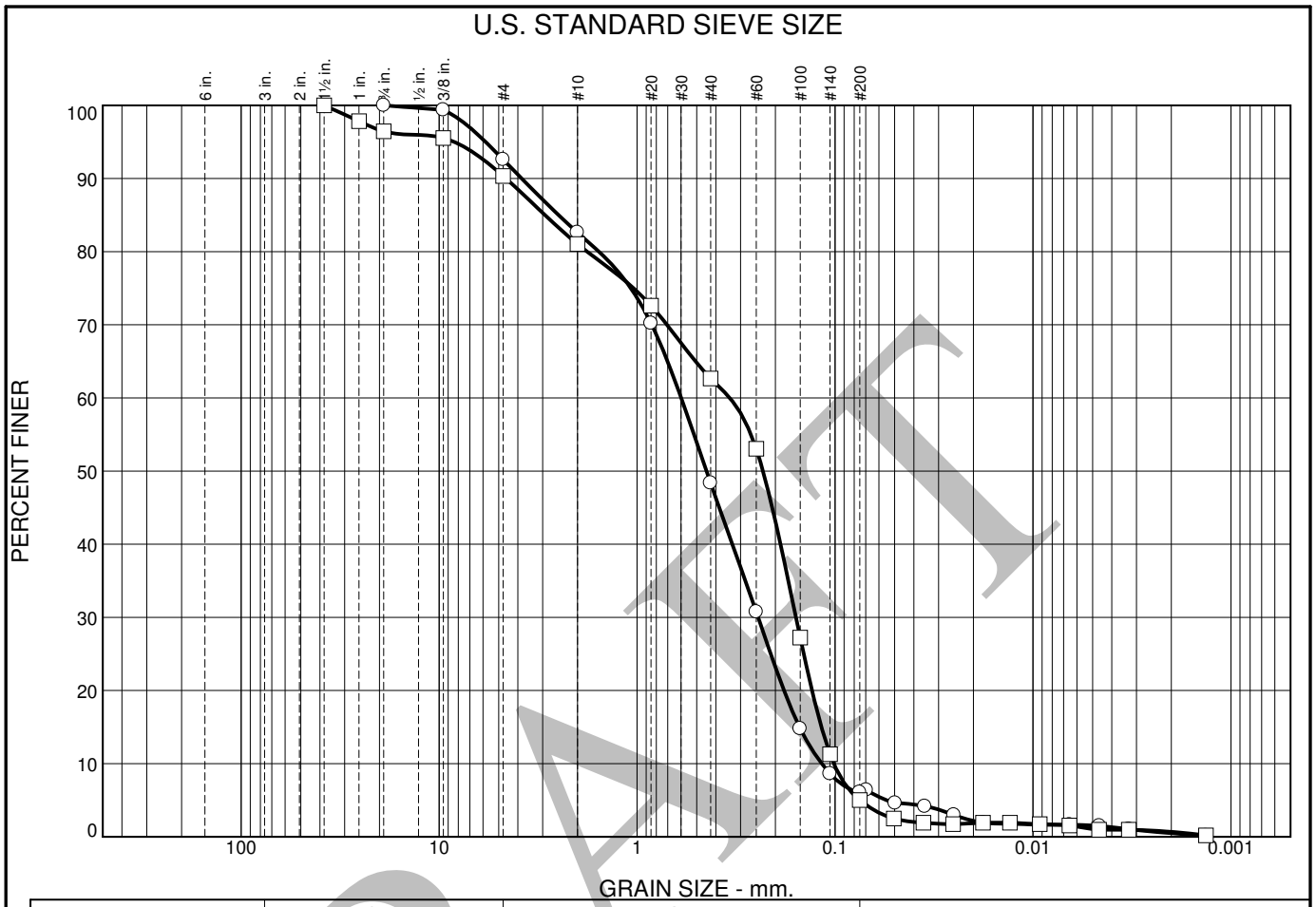
Bridge Nos. M-05-013 = W-06-013 and W-06-016
Marion and Wareham, Massachusetts

GRAIN SIZE DISTRIBUTION

DATE: 6/19/2018

FILE NO: 40991-005

DRAFT



	% +3"	% Gravel		% Sand			% Fines	
		Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
○	0.0	0.0	7.4	10.0	34.2	42.3	5.6	0.5
□	0.0	3.6	6.1	9.3	18.3	57.7	4.3	0.7

	Expl. No.	Sample No.	Depth (m.)	Atterberg Limits %			Water Content (%)	C_u	C_c	USCS
				W_L	W_P	I_P				
○	Marion	Overbank	0.0-12.0 inches				23.8	5.13	0.86	SP-SM
□	Wareham	Overbank	0.0-12.0 inches				21.0	3.35	0.72	SP-SM

	Sample Description
○	Dark brown poorly graded sand with silt
□	Brown poorly graded sand with silt

Remarks:

HALEY ALDRICH

Bridge Nos. M-05-013 = W-06-013 and W-06-016
Marion and Wareham, Massachusetts

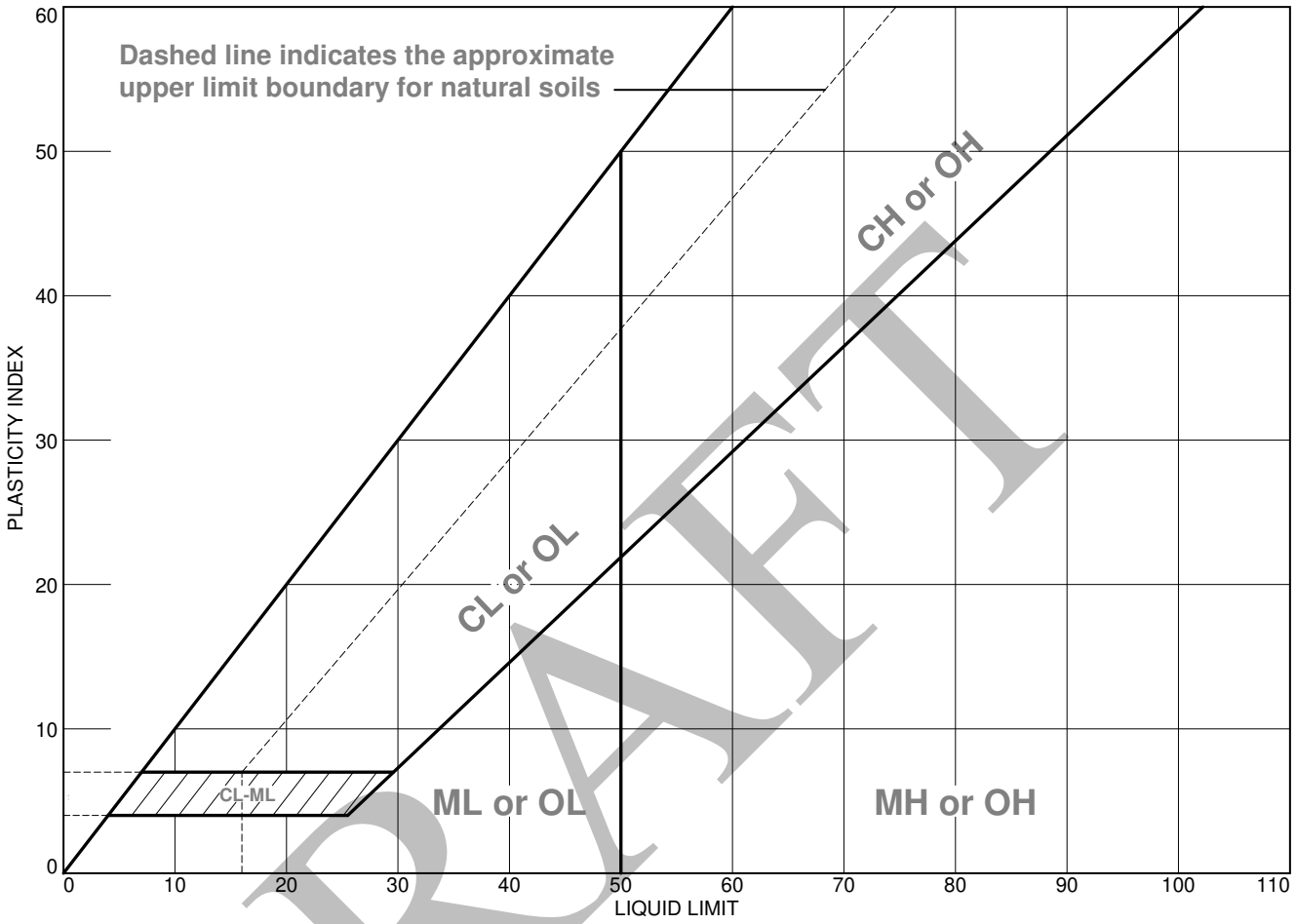
GRAIN SIZE DISTRIBUTION

DATE: 6/19/2018

FILE NO: 40991-005

DRAFT

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Light brown silt		NP				ML
■	Olive silty gravel with sand		NP		45.5	31.2	GM

Project No. 40991-005 **Client:**

Project: Bridge No. W-06-016

Wareham, Massachusetts

●**Source of Sample:** BB-9 **Depth:** 10.5-12.5 ft. **Sample Number:** S06

■**Source of Sample:** BB-10 **Depth:** 8.0-10.0 ft. **Sample Number:** S05

Remarks:

HALEY ALDRICH

Figure 40991-005

DRAFT

Appendix C. Hydrologic Analysis

Scientific Investigations Rport 2016-5156 USGS Magnitude of Flood Flows at Selected Annual Exceedance Probabilites for Streams in Massachusetts

Magnitude of Flood Flows at Ungaged Streams

Development of regional flood flow equations:
-compilation of basin characterisitics
-exploratory analysis to evaluate the best explanatory variables and their transformations
-use of robust regression methods to develop the final equations and uncertainty of the estimates

Basin Characteristic	Name	Ranges of selected basin characteristic values considered in the development of equations			Value used for Calculations
		Minimum	Mean	Maximum	
Drainage Area, sq. miles (untransformed)	DRNAREA	0.16	52.8	512	89.5
Storage, % of basin area in open water and wetlands	LC06STOR	0	9.14	32.3	25.1
Mean Basin elevation, ft	ELEV	81	758	1949	83.9

$$Q_{50} = 10^{\left[1.631+0.801\times\log_{10}(DRNAREA)+0.589\times0.001\times\left(\frac{ELEV}{3.28084}\right)-1.137\times0.01\times(LC06STOR)\right]}, \quad (2)$$

$$Q_{20} = 10^{\left[1.851+0.789\times\log_{10}(DRNAREA)+0.641\times0.001\times\left(\frac{ELEV}{3.28084}\right)-1.132\times0.01\times(LC06STOR)\right]}, \quad (3)$$

$$Q_{10} = 10^{\left[1.969+0.782\times\log_{10}(DRNAREA)+0.682\times0.001\times\left(\frac{ELEV}{3.28084}\right)-1.126\times0.01\times(LC06STOR)\right]}, \quad (4)$$

$$Q_{4} = 10^{\left[2.098+0.775\times\log_{10}(DRNAREA)+0.729\times0.001\times\left(\frac{ELEV}{3.28084}\right)-1.129\times0.01\times(LC06STOR)\right]}, \quad (5)$$

$$Q_{2} = 10^{\left[2.182+0.771\times\log_{10}(DRNAREA)+0.760\times0.001\times\left(\frac{ELEV}{3.28084}\right)-1.134\times0.01\times(LC06STOR)\right]}, \quad (6)$$

$$Q_{1} = 10^{\left[2.256+0.767\times\log_{10}(DRNAREA)+0.790\times0.001\times\left(\frac{ELEV}{3.28084}\right)-1.137\times0.01\times(LC06STOR)\right]}, \quad (7)$$

$$Q_{0.5} = 10^{\left[2.325+0.764\times\log_{10}(DRNAREA)+0.816\times0.001\times\left(\frac{ELEV}{3.28084}\right)-1.148\times0.01\times(LC06STOR)\right]}, \text{ and} \quad (8)$$

$$Q_{0.2} = 10^{\left[2.408+0.760\times\log_{10}(DRNAREA)+0.849\times0.001\times\left(\frac{ELEV}{3.28084}\right)-1.158\times0.01\times(LC06STOR)\right]}, \quad (9)$$

where

$Q_{50}, \ldots, Q_{0.2}$ are flow magnitudes for 50- to 0.2-percent AEP floods, in cubic feet per second;

DRNAREA is the drainage area of the basin, in square miles;

ELEV is the mean elevation of the basin, in feet; and

LC06STOR is the total storage defined by the percent basin area classified as wetlands and open water.

AEP	Year	Flow (cfs)
50%	2	839
20%	5	1328
10%	10	1698
4%	25	2217
2%	50	2639
1%	100	3074
0.50%	200	3538
0.20%	500	4190

Appendix D. Hydraulic Analysis

SRH-2D Project Summary Report

Project file name: Marion_Wareham.sms

Report generation date: 19 September 2024 12:39:57

Contents

1 Project summary
2 Versions of software used
3 Project datum
4 Terrain data
    4.1 Summary of scatter sets

5 Mesh summary
6 Summary of boundary conditions
7 Summary of monitor coverages
8 Summary of obstructions
9 Summary of bridges
10 Materials roughness summary
11 Simulation summary

Project summary

- Project name: Marion_Wareham
- River: Weweantic River
- Project purpose/focus: MassDOT is replacing the Marion-Wareham Bridges over the Weweantic River (Bridge Numbers M-05-001=W-06-013 and W-06-016) along Route 6, also known as Marion Road or Wareham Road. The existing and proposed conditions were modeled with the riverine floods and the coastal surges (with and without RSLR). The SRH-2D model was used to obtain parameters that are used to calculate scour.
- Model developer name: Meagan Brown
- Source of terrain data: The National Oceanic and Atmospheric Administration (NOAA) houses the Continuously Updated Digital Elevation Model (CUDEM) online, which is available for download to the public. The CUDEM is a ninth arc-second 9 (~3 meters) resolution bathymetric-topographic dataset and was used as the primary elevation data source, as it can be downloaded for large areas along the coast (CIRES, 2023).
- Source of bathymetry: Survey elevation data was collected for the roadway and bridge by Surveying and Mapping Consultants on 3/18/2018. Additional bathymetric survey was provided by MassDOT on 2/7/2024.
- Source of additional survey data:

Version of SMS used

- SMS: 13.3

Project datum

- Horizontal: NAD83_National_Spatial_Reference_System_2011
- Vertical:

Terrain data

Summary of scatter sets

Scatter set	Number of points	Minimum elevation	Maximum elevation	
Existing Survey LiDAR	18184587	-57.9370574951	126.9667892456	PROJCS["NAD_1983_2011_StatePlane_Massachusetts_Mnld_FIPS_2001_FtUS'
ProposedSurveyLiDAR	18187587	-57.9370574951	126.9667892456	PROJCS["NAD_1983_2011_StatePlane_Massachusetts_Mnld_FIPS_2001_FtUS'

- Scatter set name: Existing Survey LiDAR
    - Notes

      No notes.

- Scatter set plot

  No plot available.

- Scatter set name: ProposedSurveyLiDAR
  - Notes

    No notes.

  - Scatter set plot

    No plot available.

Mesh summary

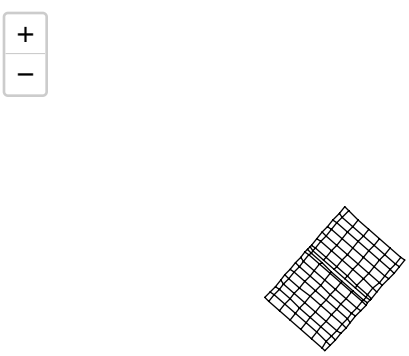
Meshes

Mesh	X size	Y size	Number of nodes	Number of elements	Smallest element size	Largest element size
Pro Bridge 013_footprint_grid	152.87050164	157.3549438003	144	114	4.2500000006	12.2908333517
Pro Bridge 016_footprint_grid	184.25522927	193.6755913999	224	179	4.2499999677	11.7913236739
Existing Mesh	7299.0	9794.0	15832	22047	3.3471269993	215.9223177853
Proposed Mesh	7299.0	9794.0	15093	20484	1.4737889792	217.6453369345

- Mesh name: Pro Bridge 013_footprint_grid
  - Notes

    No notes.

  - Mesh plot

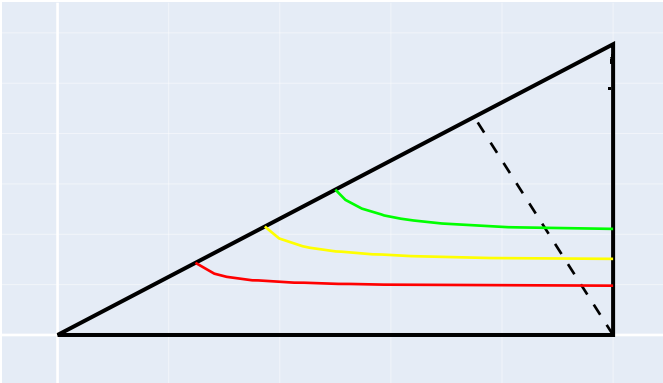


Leaflet (https://leafletjs.com) | Data by © OpenStreetMap (http://openstreetmap.org), under ODbL (http://www.openstreetmap.org/copyright).

  - Mesh quality report

    The data points represent the worst 100 elements. Any points below the red line correspond to poor quality elements.

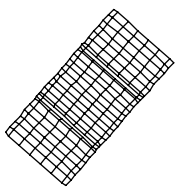
Q(ALS)



- Mesh name: Pro Bridge 016_footprint_grid
  - Notes

    No notes.

  - Mesh plot

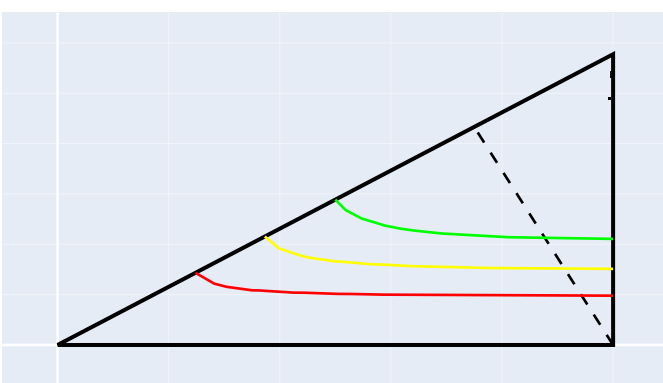


Leaflet (https://leafletjs.com) | Data by © OpenStreetMap (http://openstreetmap.org), under ODbL (http://www.openstreetmap.org/copyright).

  - Mesh quality report

    The data points represent the worst 100 elements. Any points below the red line correspond to poor quality elements.

Q(ALS)



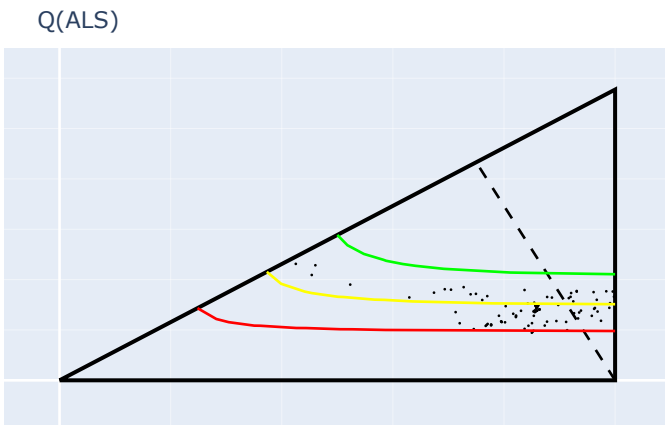
- Mesh name: Existing Mesh
  - Notes

Type	DateTime	Note
SMS	2024-05-24 22:55:59	Created from 'Map -> 2D Mesh' command with coverage "2D Existing Mesh Gen".

- Mesh plot

- Mesh quality report

  The data points represent the worst 100 elements. Any points below the red line correspond to poor quality elements.



- Mesh name: Proposed Mesh
  - Notes

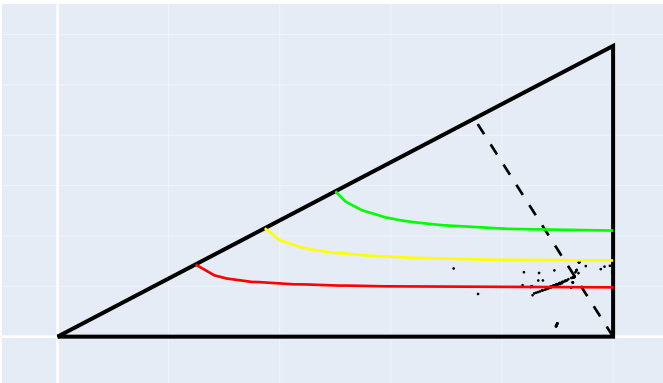
    No notes.

  - Mesh plot

- Mesh quality report

  The data points represent the worst 100 elements. Any points below the red line correspond to poor quality elements.

  Q(ALS)



Summary of boundary conditions

- Coverage: "Woods Hole Tidal 500-yr"
  - Notes

    No notes.

  - Number of boundary condition arcs: 3

    Inlet-Q

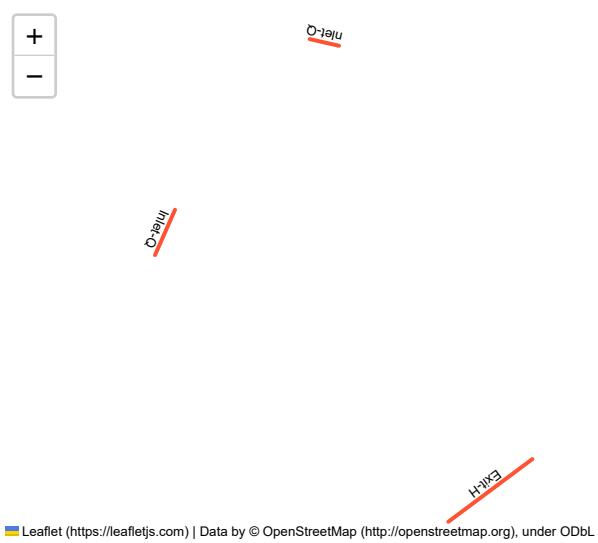
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance

    Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA

  - Hydraulic structures
    - Number of hydraulic structures: 0

  - BC coverage plot



Leaflet (https://leafletjs.com) | Data by © OpenStreetMap (http://openstreetmap.org), under ODbL (http://www.openstreetmap.org/copyright).

- Coverage: "Woods Hole Tidal 200-yr"
  - Notes

No notes.

- Number of boundary condition arcs: 3

Inlet-Q

Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA

- Hydraulic structures
  - Number of hydraulic structures: 0

- BC coverage plot

- Coverage: "Woods Hole Tidal 100-yr"
  - Notes

No notes.

- Number of boundary condition arcs: 3

Inlet-Q

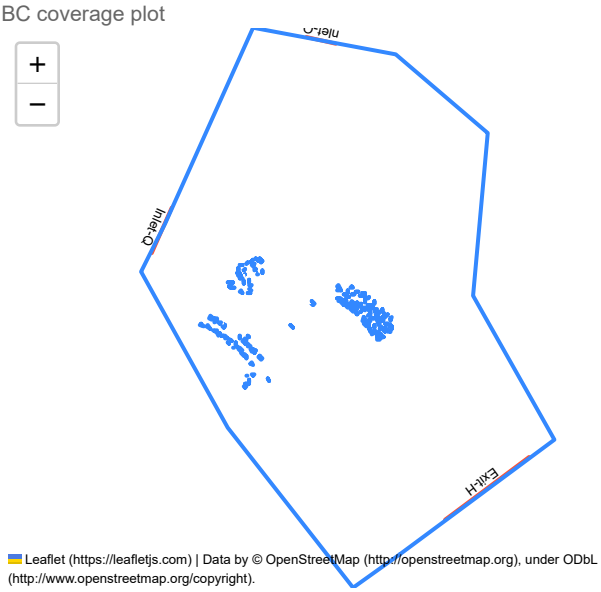
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA

- Hydraulic structures
  - Number of hydraulic structures: 0

- BC coverage plot



- Coverage: "Woods Hole Tidal 50-yr"
  - Notes

    No notes.

  - Number of boundary condition arcs: 3

Inlet-Q

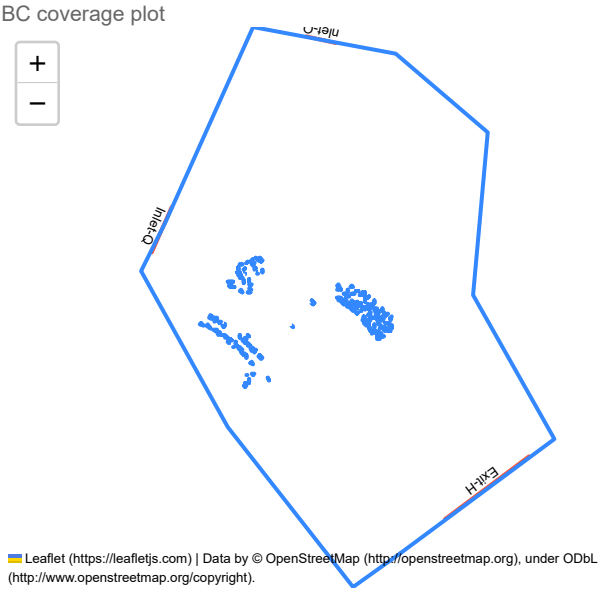
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA

  - Hydraulic structures
    - Number of hydraulic structures: 0

  - BC coverage plot



- Coverage: "Woods Hole Tidal 25-yr"
  - Notes

    No notes.

- Number of boundary condition arcs: 3

Inlet-Q

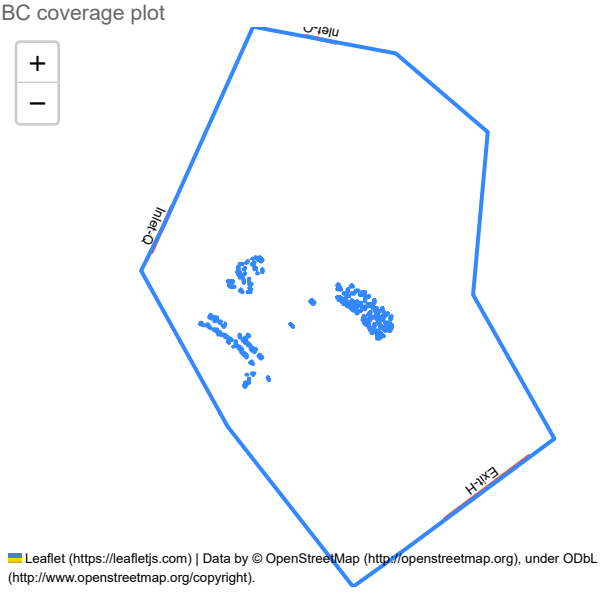
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA

- Hydraulic structures
  - Number of hydraulic structures: 0

- BC coverage plot



- Coverage: "Woods Hole Tidal 10-yr"
  - Notes

    No notes.

  - Number of boundary condition arcs: 3

Inlet-Q

Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA

- Hydraulic structures
  - Number of hydraulic structures: 0

- BC coverage plot

- Coverage: "Coastal 25-yr BC"
  - Notes

    No notes.

  - Number of boundary condition arcs: 5

Inlet-Q

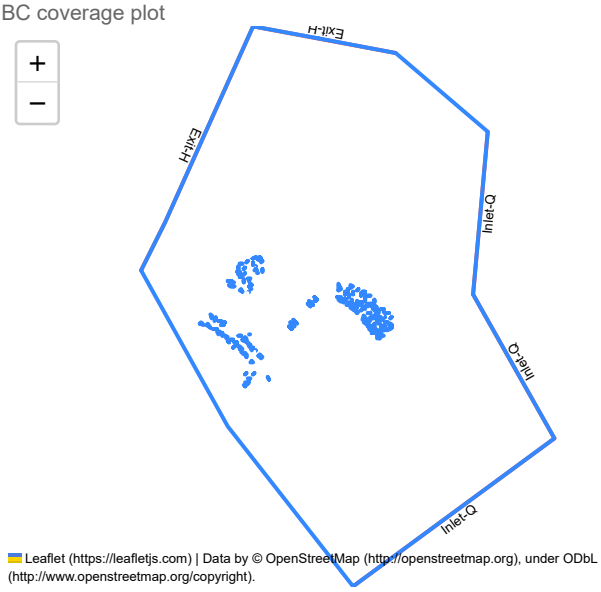
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA

  - Hydraulic structures
    - Number of hydraulic structures: 0

  - BC coverage plot



- Coverage: "Coastal 50-yr BC"
  - Notes

No notes.

- Number of boundary condition arcs: 6

Inlet-Q

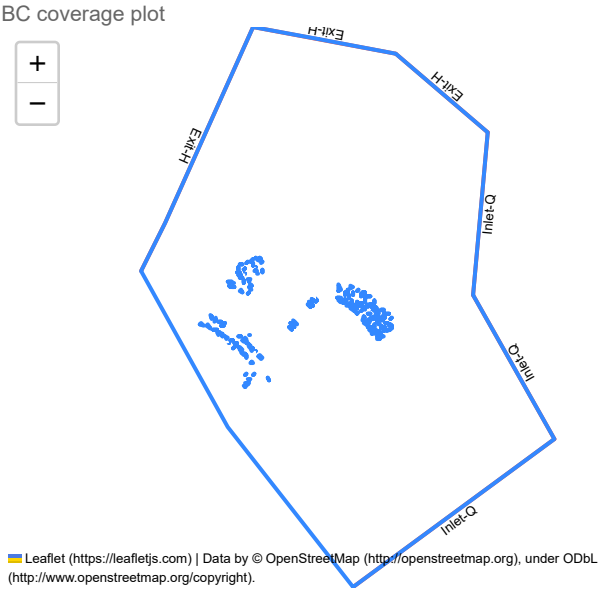
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

- Hydraulic structures
  - Number of hydraulic structures: 0

- BC coverage plot



- Coverage: "Coastal 50-yr RSLR BC"
  - Notes

No notes.

- Number of boundary condition arcs: 6

Inlet-Q

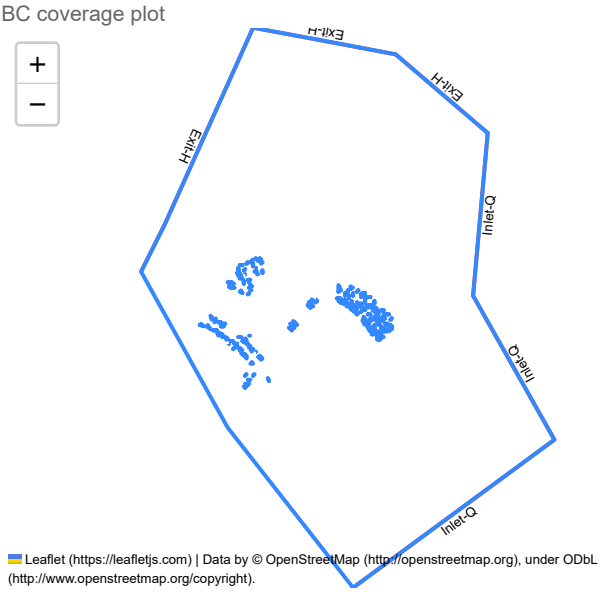
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

- Hydraulic structures
  - Number of hydraulic structures: 0

- BC coverage plot



- Coverage: "Coastal 100-yr BC"
  - Notes

    No notes.

  - Number of boundary condition arcs: 6

Inlet-Q

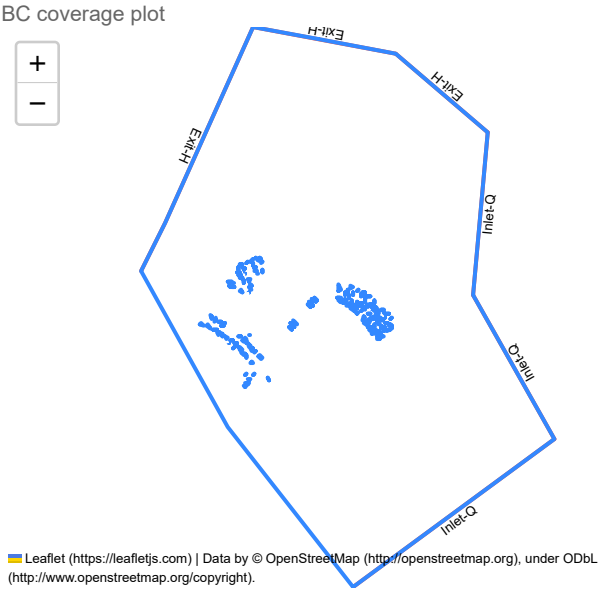
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

  - Hydraulic structures
    - Number of hydraulic structures: 0

  - BC coverage plot



- Coverage: "Coastal 100-yr RSLR BC"
  - Notes

No notes.

- Number of boundary condition arcs: 6

Inlet-Q

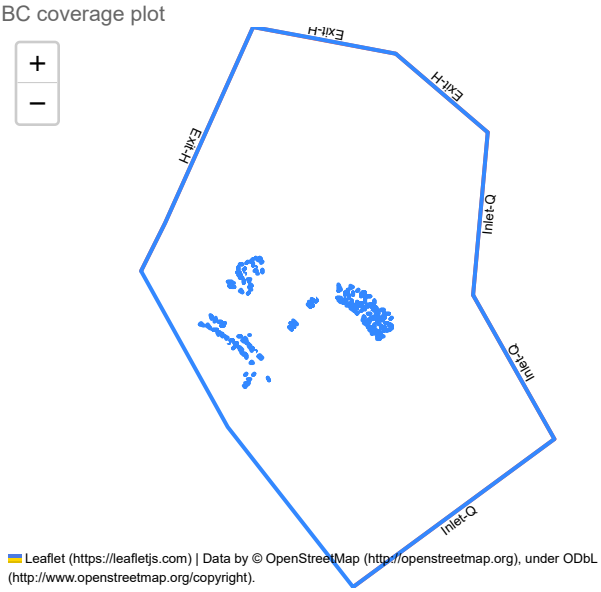
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

- Hydraulic structures
  - Number of hydraulic structures: 0

- BC coverage plot



- Coverage: "Coastal 500-yr BC"
  - Notes

No notes.

- Number of boundary condition arcs: 6

Inlet-Q

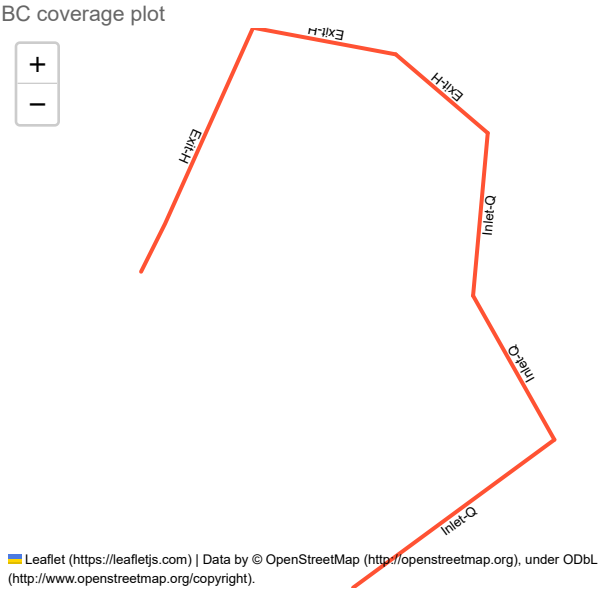
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

- Hydraulic structures
  - Number of hydraulic structures: 0

- BC coverage plot



- Coverage: "Coastal 500-yr RSLR BC"
  - Notes

    No notes.

  - Number of boundary condition arcs: 6

Inlet-Q

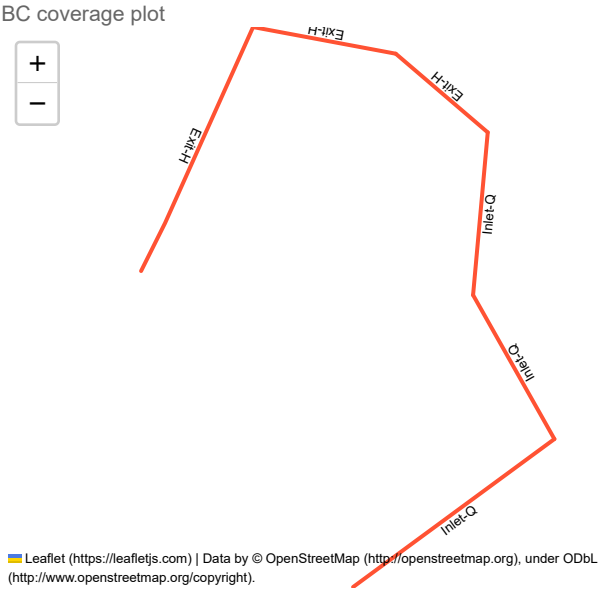
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

  - Hydraulic structures
    - Number of hydraulic structures: 0

  - BC coverage plot



- Coverage: "Coastal 25-yr BC"
  - Notes

No notes.

- Number of boundary condition arcs: 5

Inlet-Q

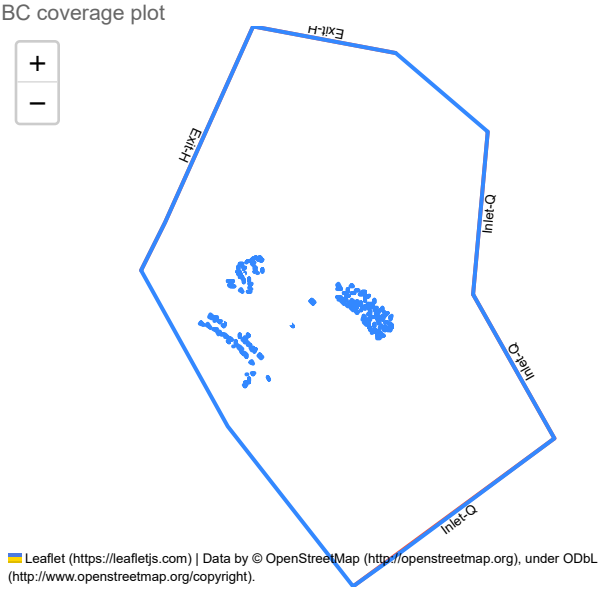
Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA

- Hydraulic structures
  - Number of hydraulic structures: 0

- BC coverage plot



- Coverage: "Coastal 50-yr BC Existing"
  - Notes

No notes.

- Number of boundary condition arcs: 6

Inlet-Q

Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

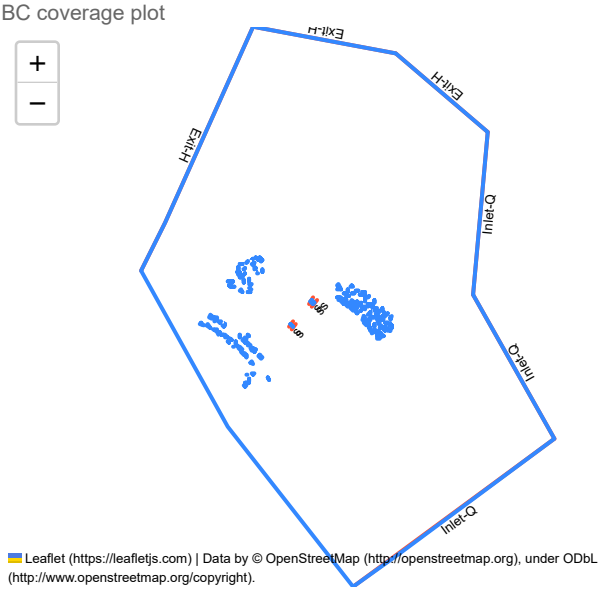
Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

- Hydraulic structures
  - Number of hydraulic structures: 2

Pressure

Upstream arc	Downstream arc	Ceiling type	Upstream elevation	Downstream elevation	Roughness
8	7	Parabolic	6.32	6.368	0.08
10	9	Parabolic	8.42	8.561	0.08

- BC coverage plot



- Coverage: "Coastal 50-yr RSLR BC Existing"
  - Notes

    No notes.

  - Number of boundary condition arcs: 6

Inlet-Q

Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

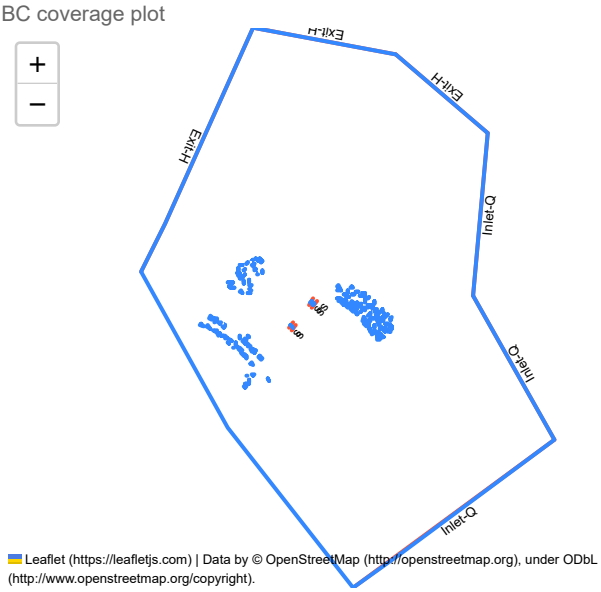
Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

  - Hydraulic structures
    - Number of hydraulic structures: 2

Pressure

Upstream arc	Downstream arc	Ceiling type	Upstream elevation	Downstream elevation	Roughness
8	7	Parabolic	6.32	6.368	0.08
10	9	Parabolic	8.42	8.516	0.08

- BC coverage plot



- Coverage: "Coastal 100-yr BC Existing"
  - Notes

    No notes.

  - Number of boundary condition arcs: 6

Inlet-Q

Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

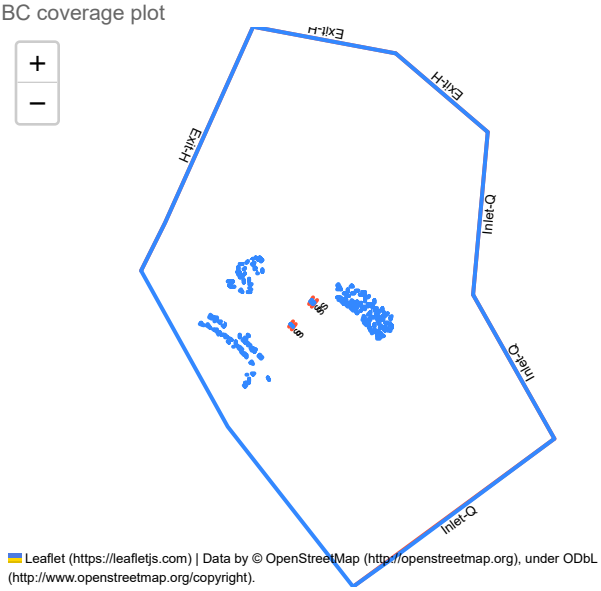
Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

  - Hydraulic structures
    - Number of hydraulic structures: 2

Pressure

Upstream arc	Downstream arc	Ceiling type	Upstream elevation	Downstream elevation	Roughness
8	7	Parabolic	6.32	6.368	0.08
10	9	Parabolic	8.42	8.516	0.08

- BC coverage plot



- Coverage: "Coastal 100-yr RSLR BC Existing"
  - Notes

    No notes.

  - Number of boundary condition arcs: 6

Inlet-Q

Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

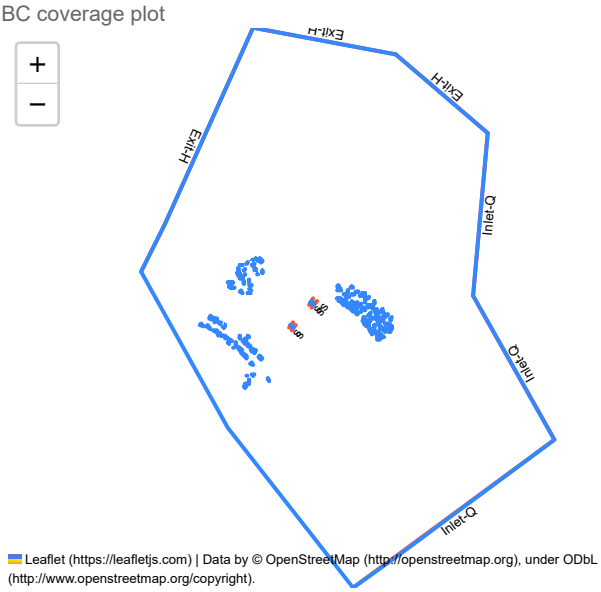
Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

  - Hydraulic structures
    - Number of hydraulic structures: 2

Pressure

Upstream arc	Downstream arc	Ceiling type	Upstream elevation	Downstream elevation	Roughness
8	7	Parabolic	6.32	6.368	0.08
10	9	Parabolic	8.42	8.516	0.08

- BC coverage plot



- Coverage: "Coastal 500-yr BC Existing"
  - Notes

    No notes.

  - Number of boundary condition arcs: 6

Inlet-Q

Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

  - Hydraulic structures
    - Number of hydraulic structures: 2

Pressure

Upstream arc	Downstream arc	Ceiling type	Upstream elevation	Downstream elevation	Roughness
8	7	Parabolic	6.32	6.368	0.08
10	9	Parabolic	8.42	8.516	0.08

- BC coverage plot

- Coverage: "Coastal 500-yr RSLR BC Existing"
  - Notes

    No notes.

  - Number of boundary condition arcs: 6

Inlet-Q

Arc	Discharge option	Constant Q	Distribution at inlet
1	Time series		Conveyance
3	Time series		Conveyance
4	Time series		Conveyance

Exit-H

Arc	Water surface (WSE) option	Constant wse	Channel calculator	Cross section plot
2	Time series		NA	NA
5	Time series		NA	NA
6	Time series		NA	NA

  - Hydraulic structures
    - Number of hydraulic structures: 2

Pressure

Upstream arc	Downstream arc	Ceiling type	Upstream elevation	Downstream elevation	Roughness
8	7	Parabolic	6.32	6.368	0.08
10	9	Parabolic	8.42	8.516	0.08

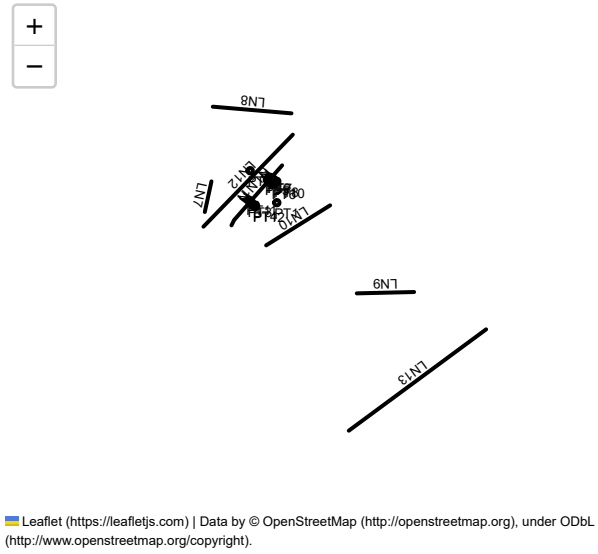
- BC coverage plot

Summary of monitor coverages

- Coverage: "Monitor Riverine"
  - Notes

    No notes.

  - Number of points: 12
  - Number of lines: 13
  - Monitor coverage plot



- Coverage: "Monitor Coastal"
  - Notes

    No notes.

  - Number of points: 12
  - Number of lines: 14

- Monitor coverage plot

Summary of obstructions

No obstruction coverages.

Summary of bridges

No bridge coverages.

Materials roughness summary

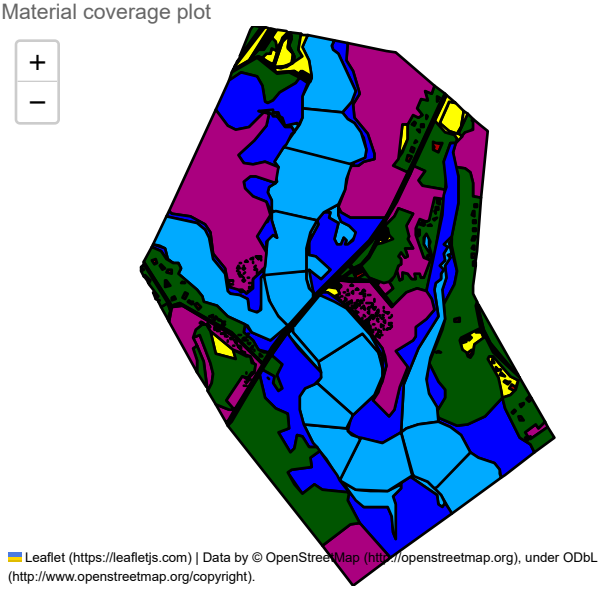
- Coverage: "Existing Materials + 0.00875 channel n"
  - Notes

    No notes.

  - Number of materials: 8

Material Name	Color	Manning's N
unassigned		0.02
Open Water		0.044
Wetlands		0.065
Road/ParkingLots		0.02
Developed Residential Area		0.1
Building		0.18
Trees		0.15
Grass		0.045

- Material coverage plot



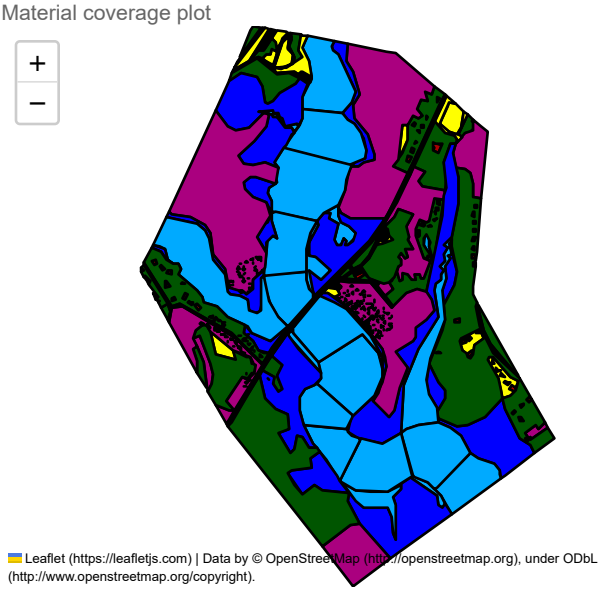
- Coverage: "Existing Materials - 0.00875 channel n"
  - Notes

    No notes.

  - Number of materials: 8

Material Name	Color	Manning's N
unassigned		0.02
Open Water		0.026
Wetlands		0.065
Road/ParkingLots		0.02
Developed Residential Area		0.1
Building		0.18
Trees		0.15
Grass		0.045

  - Material coverage plot



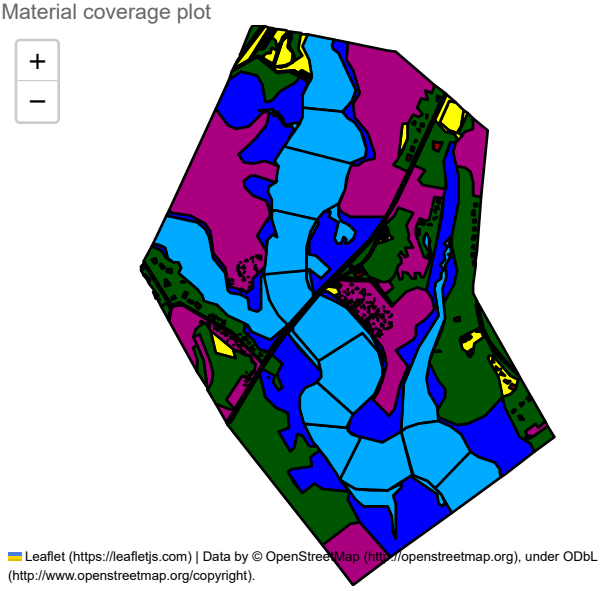
- Coverage: "Existing Materials"
  - Notes

    No notes.

- Number of materials: 8

Material Name	Color	Manning's N
unassigned		0.02
Open Water		0.035
Wetlands		0.065
Road/ParkingLots		0.02
Developed Residential Area		0.1
Building		0.18
Trees		0.15
Grass		0.045

- Material coverage plot



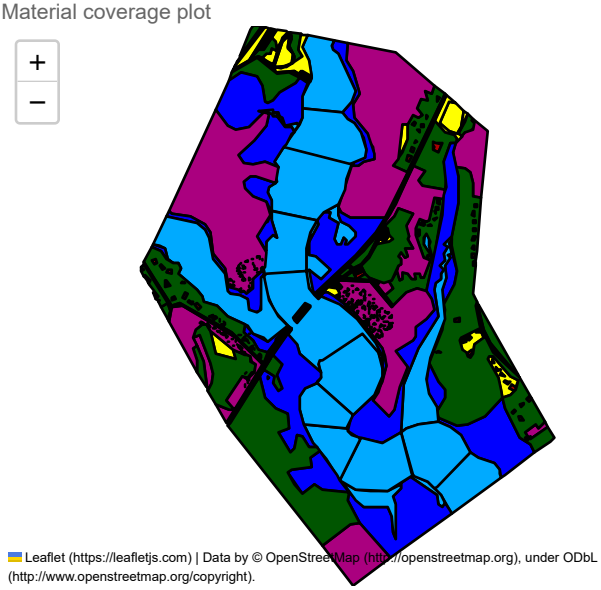
- Coverage: "Proposed Materials"
  - Notes

    No notes.

  - Number of materials: 9

Material Name	Color	Manning's N
unassigned		0.02
Open Water/Channel		0.035
Wetlands		0.065
Road/ParkingLots		0.02
Developed Residential Area		0.1
Building		0.18
Trees		0.15
Grass		0.045
RipRap Bank Protection		0.06

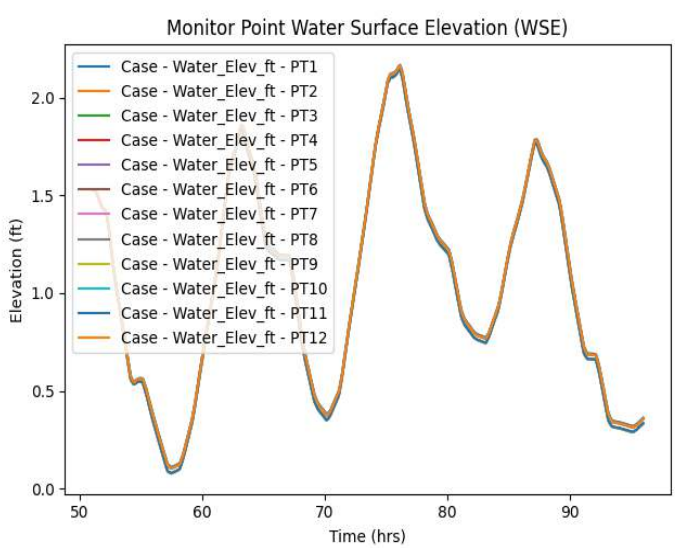
- Material coverage plot

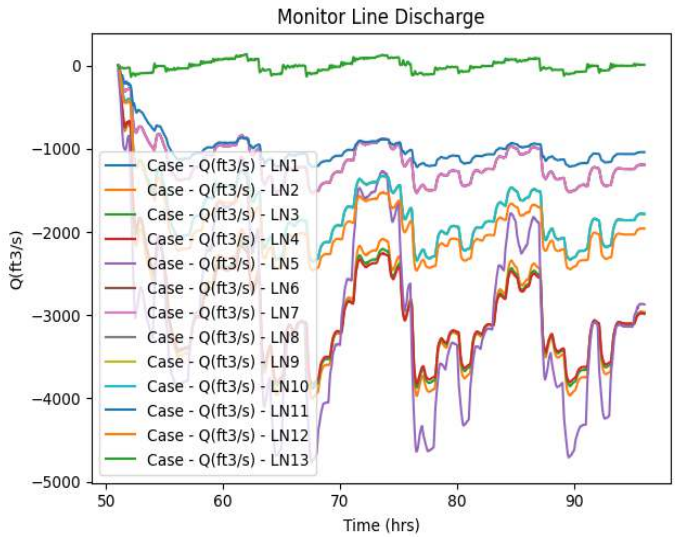


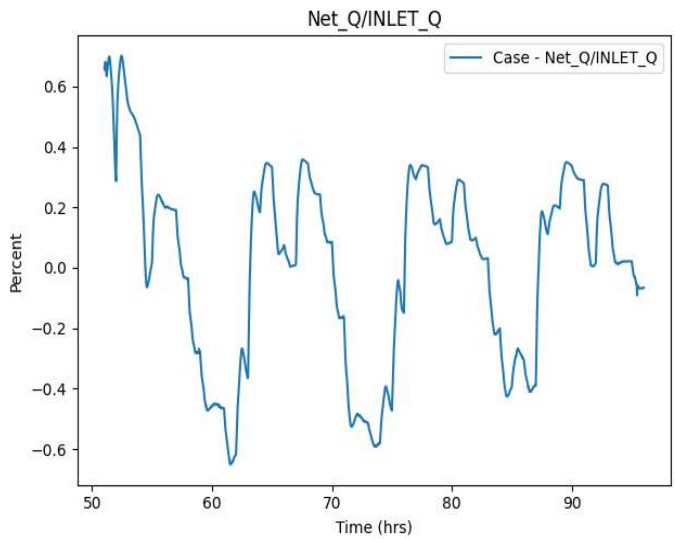
Simulation summary

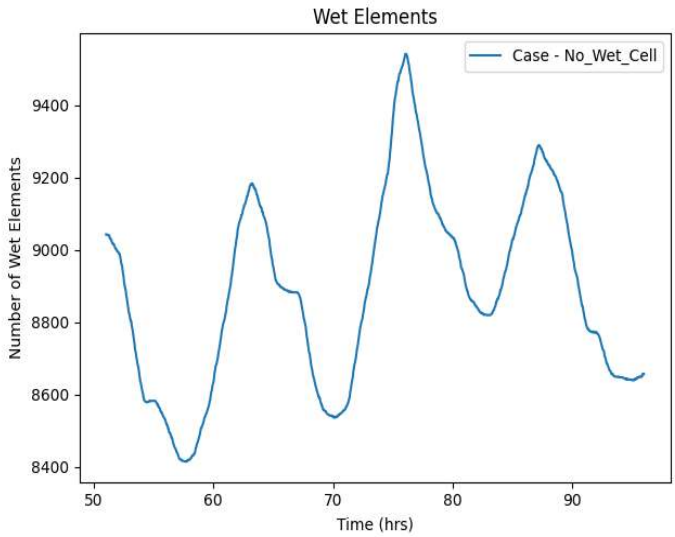
- Simulation name: Proposed 100-yr Woods Hole Tidal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 51.0
    - Time step (seconds): 1.0
    - End time (hours): 96.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 1.53
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

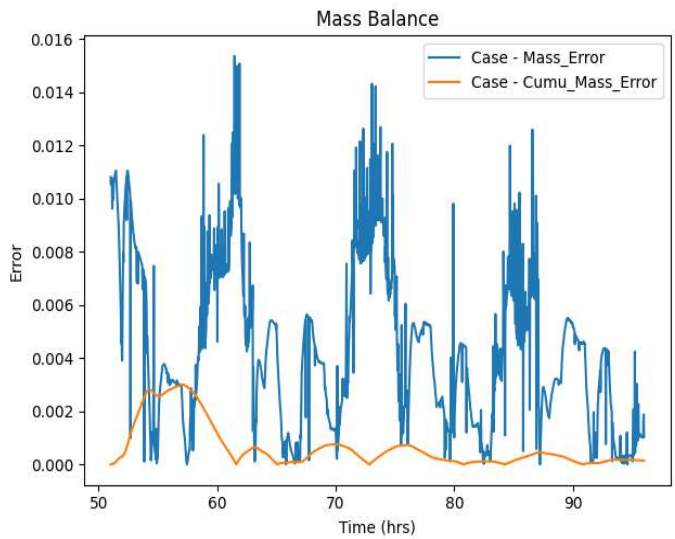
  - Mesh used: "Proposed Mesh"
  - Boundary condition coverage used: "Woods Hole Tidal 100-yr"
  - Obstructions coverage used: None
  - Materials coverage used: "Proposed Materials"
  - Monitor coverage used: "Monitor Riverine"
  - Solution plots




Monitor Line Discharge
Q(ft3/s)
Time (hrs)
Case - Q(ft3/s) - LN1
Case - Q(ft3/s) - LN2
Case - Q(ft3/s) - LN3
Case - Q(ft3/s) - LN4
Case - Q(ft3/s) - LN5
Case - Q(ft3/s) - LN6
Case - Q(ft3/s) - LN7
Case - Q(ft3/s) - LN8
Case - Q(ft3/s) - LN9
Case - Q(ft3/s) - LN10
Case - Q(ft3/s) - LN11
Case - Q(ft3/s) - LN12
Case - Q(ft3/s) - LN13


Net_Q/INLET_Q
Percent
Time (hrs)
Case - Net_Q/INLET_Q





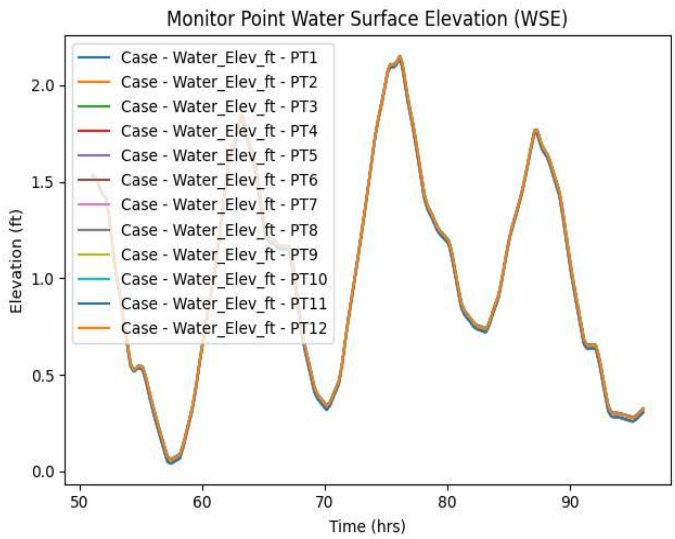
- CPU time (hours): 1.479
- Results:

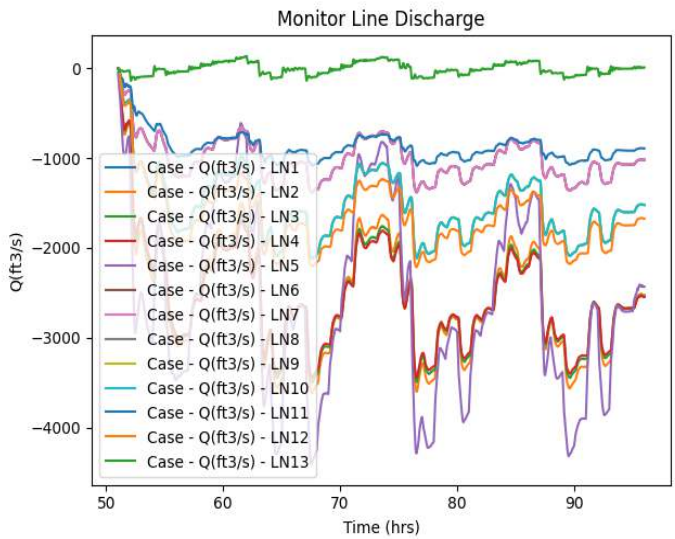
SRH-2D version: 3.6.5

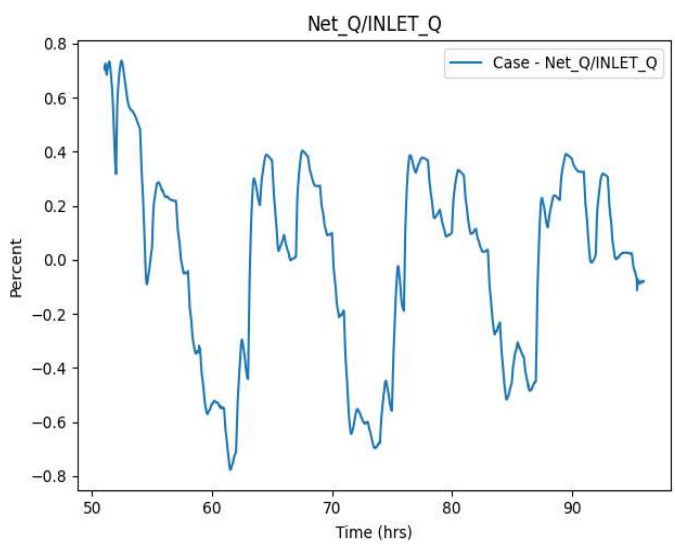
Dataset	Minimum	Maximum
Water_Elev_ft	-0.0592255332	2.2458086014
Water_Depth_ft	-6.906478405	33.2368850708
Vel_Mag_ft_p_s	0.0	2.8610527515
Froude	4.7472351164e-15	1.8665090799
B_Stress_lb_p_ft2	2.8221479023e-29	0.3689508438

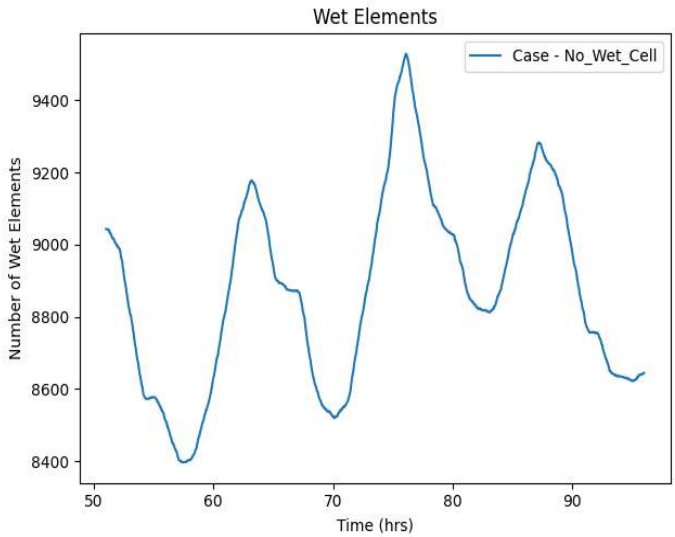
- Simulation name: Proposed 50-yr Woods Hole Tidal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 51.0
    - Time step (seconds): 1.0
    - End time (hours): 96.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 1.53
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)
  - Mesh used: "Proposed Mesh"
  - Boundary condition coverage used: "Woods Hole Tidal 50-yr"

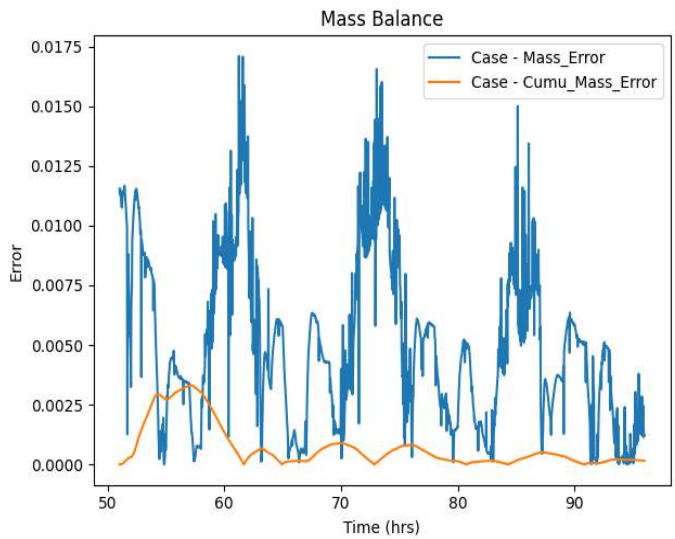
- Obstructions coverage used: None
- Materials coverage used: "Proposed Materials"
- Monitor coverage used: "Monitor Riverine"
- Solution plots











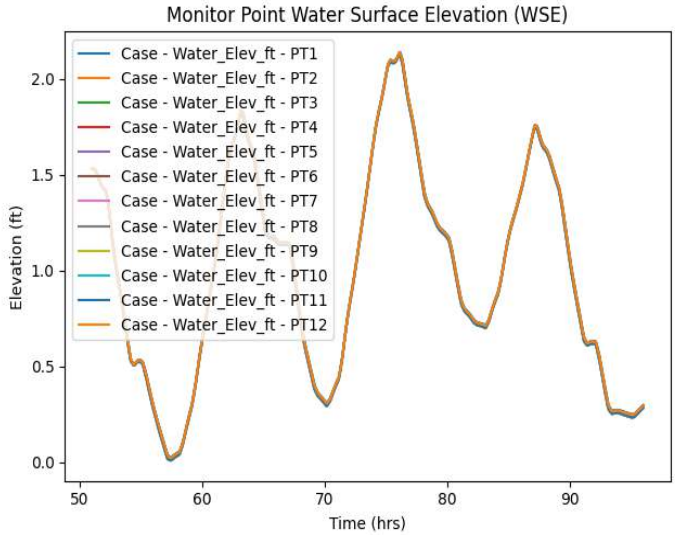
- CPU time (hours): 1.502
- Results:

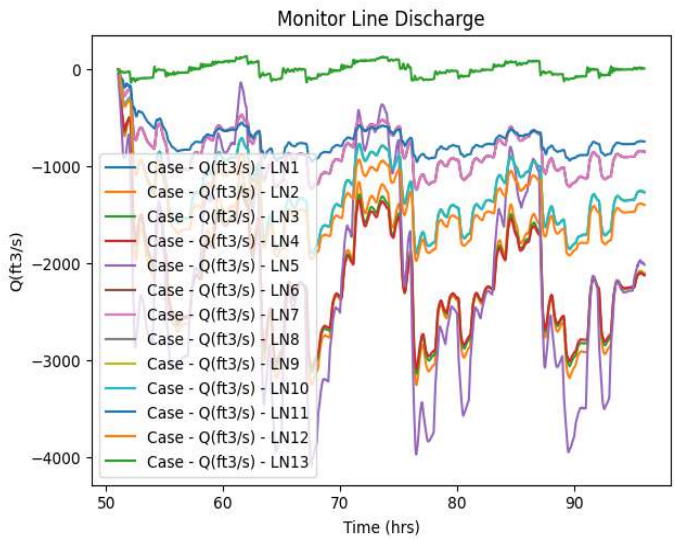
SRH-2D version: 3.6.5

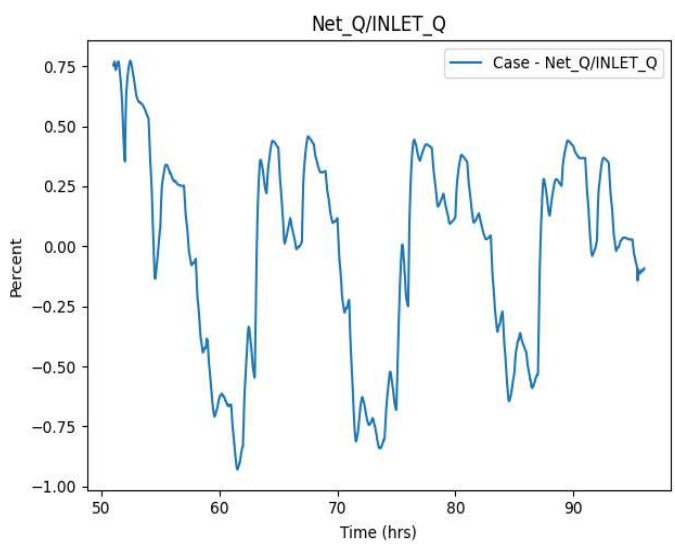
Dataset	Minimum	Maximum
Water_Elev_ft	-0.0593590327	2.2291250229
Water_Depth_ft	-6.8882393837	33.2200279236
Vel_Mag_ft_p_s	0.0	2.8634734154
Froude	4.7472351164e-15	1.612668395
B_Stress_lb_p_ft2	2.8221479023e-29	0.3850740492

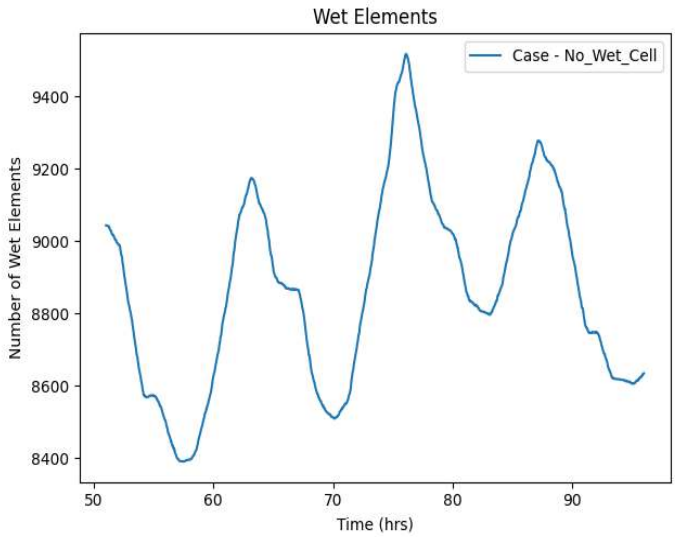
- Simulation name: Proposed 25-yr Woods Hole Tidal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 51.0
    - Time step (seconds): 1.0
    - End time (hours): 96.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 1.53
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)
  - Mesh used: "Proposed Mesh"
  - Boundary condition coverage used: "Woods Hole Tidal 25-yr"

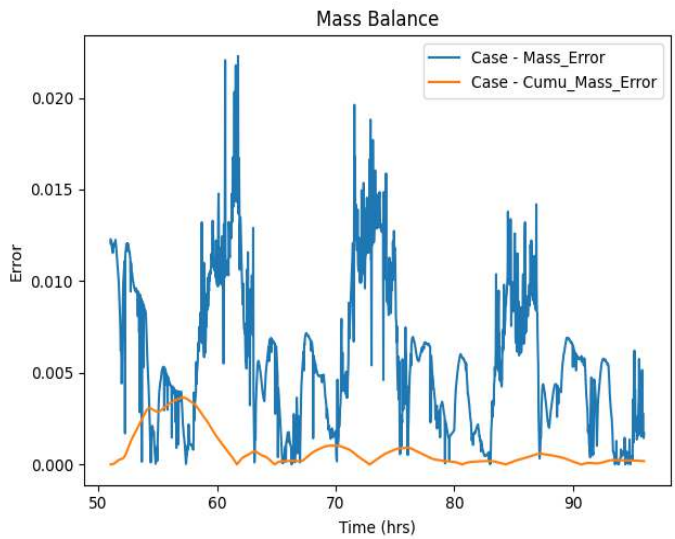
- Obstructions coverage used: None
- Materials coverage used: "Proposed Materials"
- Monitor coverage used: "Monitor Riverine"
- Solution plots











- CPU time (hours): 1.505
- Results:

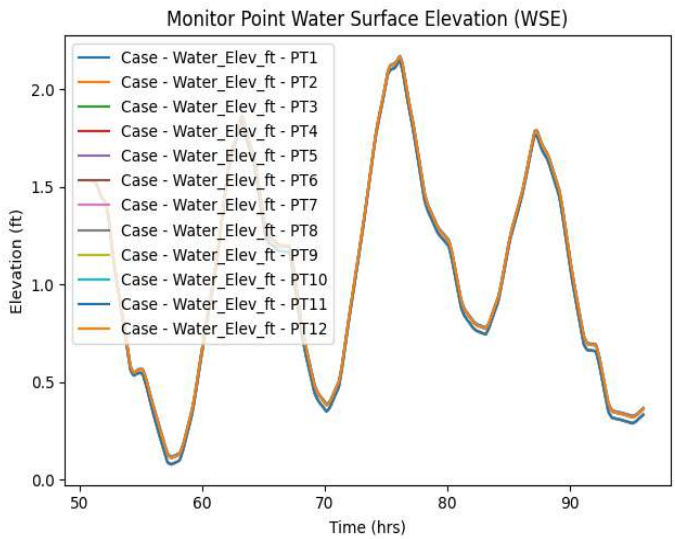
SRH-2D version: 3.6.5

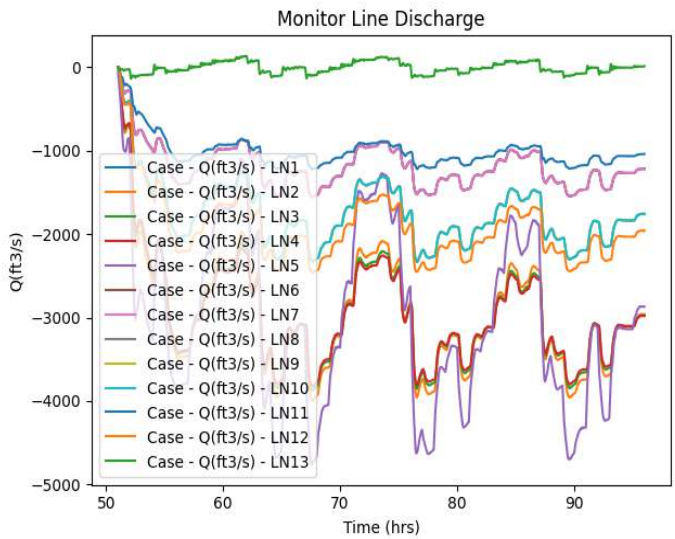
Dataset	Minimum	Maximum
Water_Elev_ft	-0.0593906604	2.1873745918
Water_Depth_ft	-6.9009466171	33.2062225342
Vel_Mag_ft_p_s	0.0	2.9485633373
Froude	4.7472351164e-15	1.3042781353
B_Stress_lb_p_ft2	2.8221479023e-29	0.4004462361

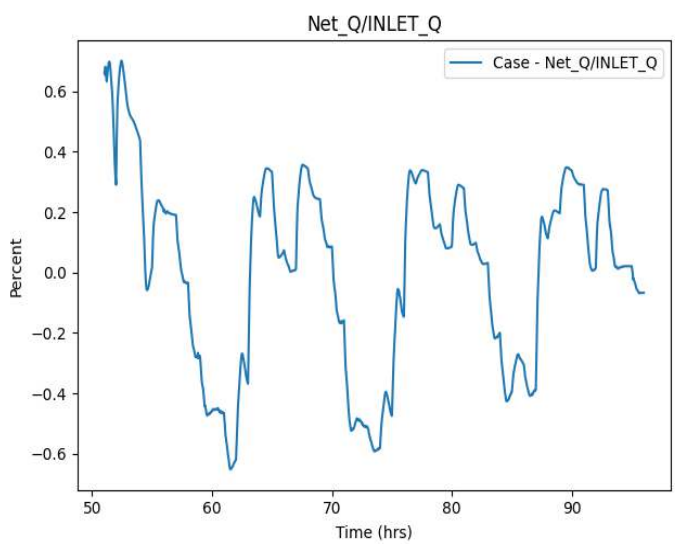
- Simulation name: Existing 100-yr Woods Hole Tidal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 51.0
    - Time step (seconds): 1.0
    - End time (hours): 96.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 1.53
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

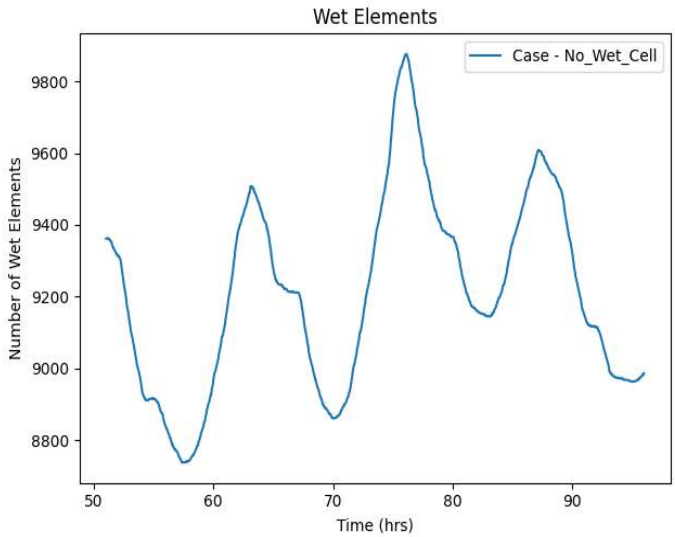
  - Mesh used: "Existing Mesh"
  - Boundary condition coverage used: "Woods Hole Tidal 100-yr"

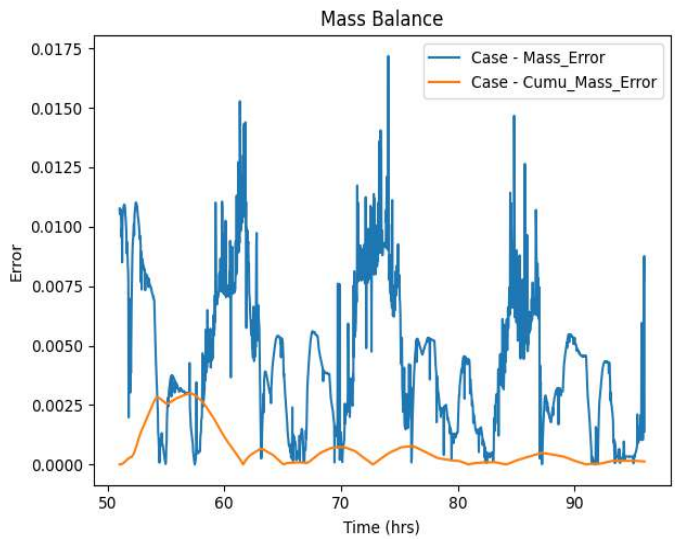
- Obstructions coverage used: None
- Materials coverage used: "Existing Materials"
- Monitor coverage used: "Monitor Riverine"
- Solution plots











- CPU time (hours): 1.52
- Results:

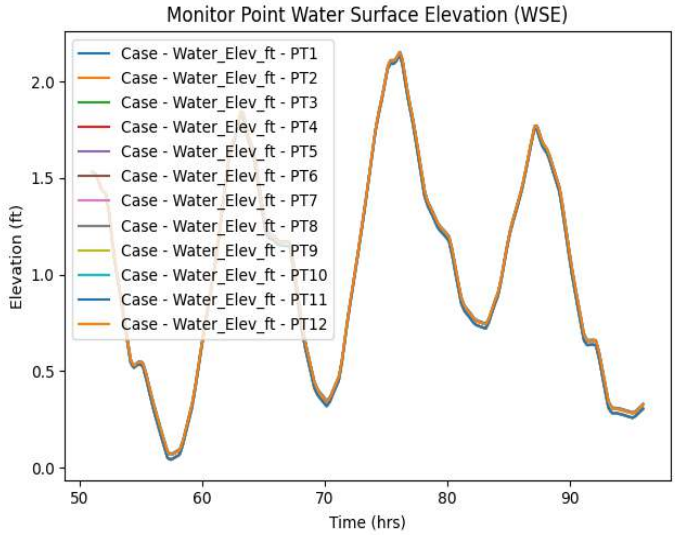
SRH-2D version: 3.6.5

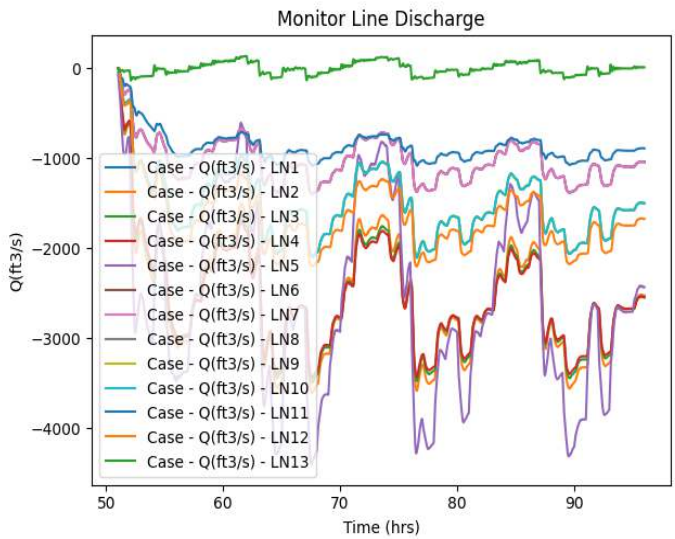
Dataset	Minimum	Maximum
Water_Elev_ft	-0.0594751686	2.2494983673
Water_Depth_ft	-10.6104040146	32.8641471863
Vel_Mag_ft_p_s	0.0	2.8418829441
Froude	1.5359638068e-15	1.6443160772
B_Stress_lb_p_ft2	5.2725036805e-30	0.3810791671

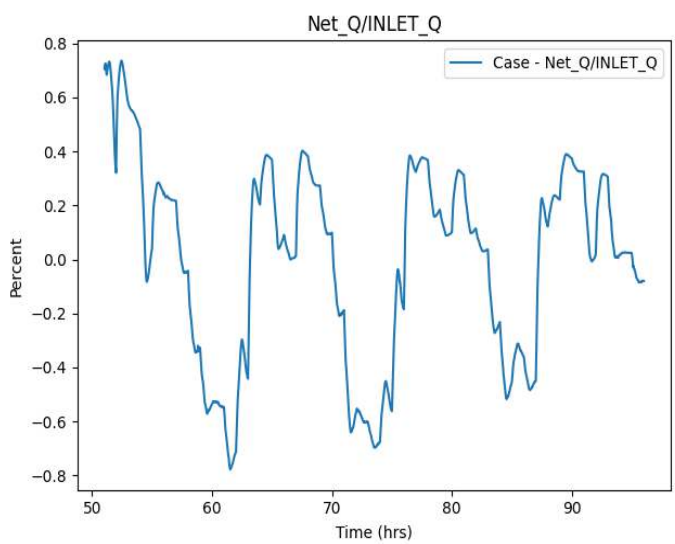
- Simulation name: Existing 50-yr Woods Hole Tidal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 51.0
    - Time step (seconds): 1.0
    - End time (hours): 96.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 1.53
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

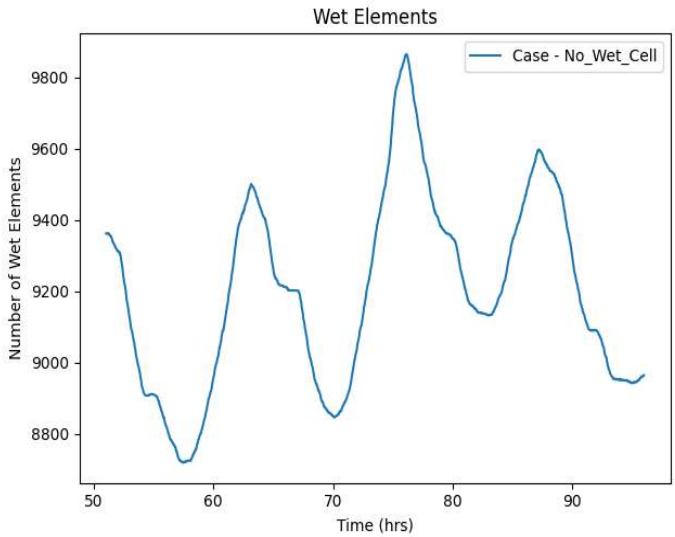
  - Mesh used: "Existing Mesh"
  - Boundary condition coverage used: "Woods Hole Tidal 50-yr"

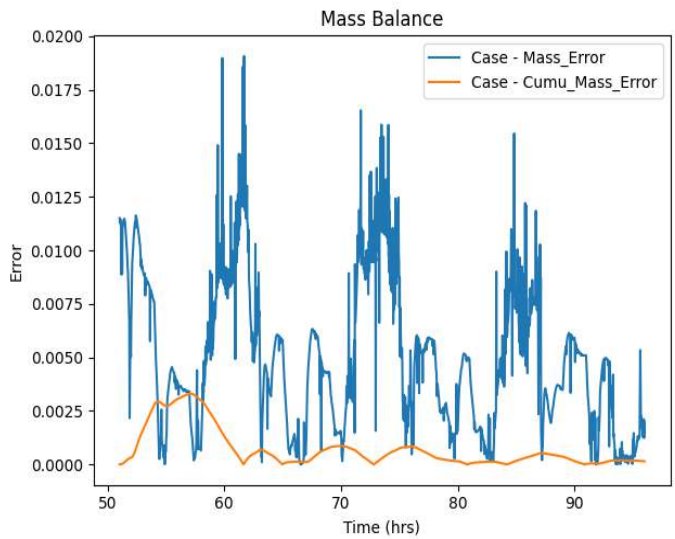
- Obstructions coverage used: None
- Materials coverage used: "Existing Materials"
- Monitor coverage used: "Monitor Riverine"
- Solution plots











- CPU time (hours): 1.525
- Results:

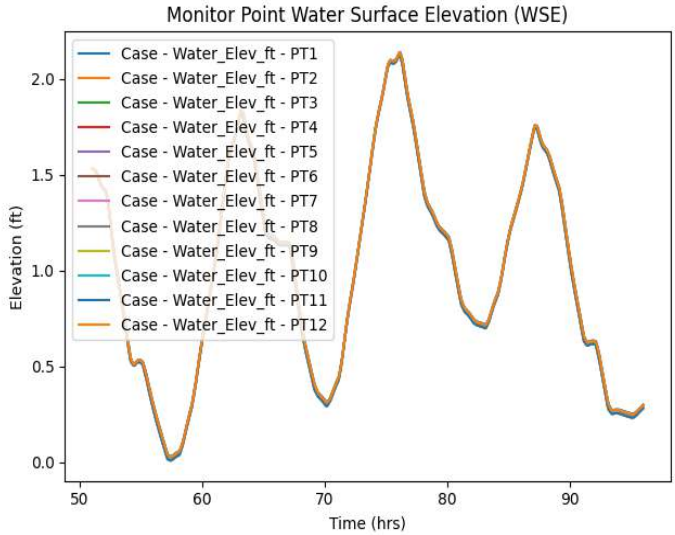
SRH-2D version: 3.6.5

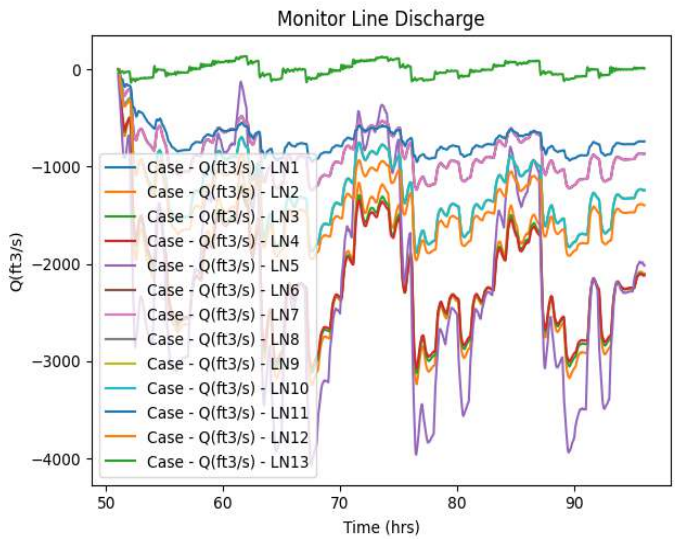
Dataset	Minimum	Maximum
Water_Elev_ft	-0.0595739931	2.22453475
Water_Depth_ft	-10.6451063156	32.8462257385
Vel_Mag_ft_p_s	0.0	2.8428113461
Froude	1.5359638068e-15	1.0931125879
B_Stress_lb_p_ft2	5.2725036805e-30	0.3988318443

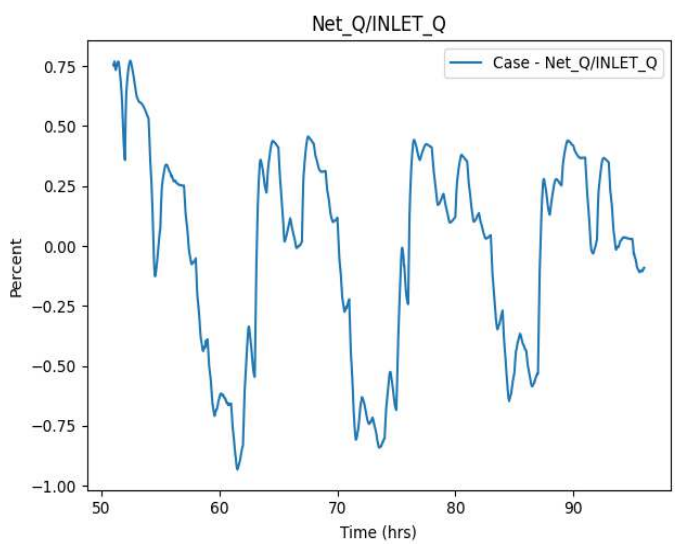
- Simulation name: Existing 25-yr Woods Hole Tidal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 51.0
    - Time step (seconds): 1.0
    - End time (hours): 96.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 1.53
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

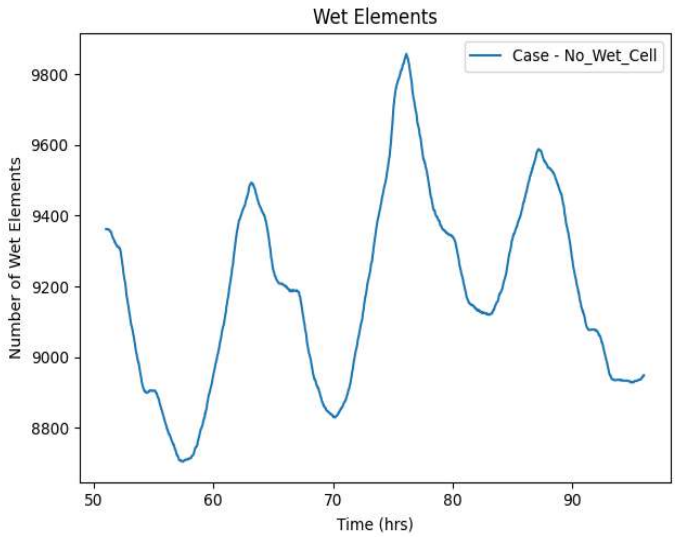
  - Mesh used: "Existing Mesh"
  - Boundary condition coverage used: "Woods Hole Tidal 25-yr"

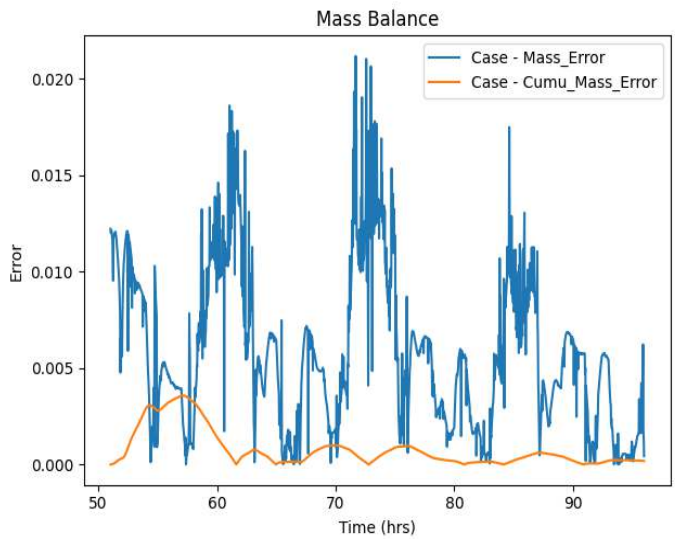
- Obstructions coverage used: None
- Materials coverage used: "Existing Materials"
- Monitor coverage used: "Monitor Riverine"
- Solution plots











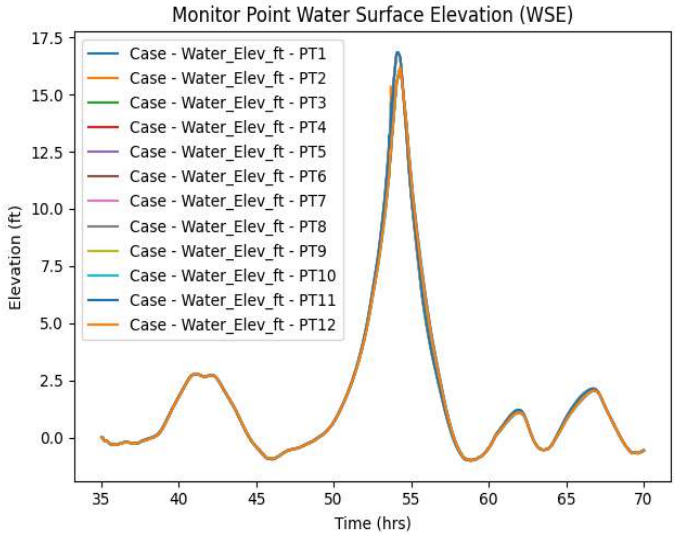
- CPU time (hours): 1.528
- Results:

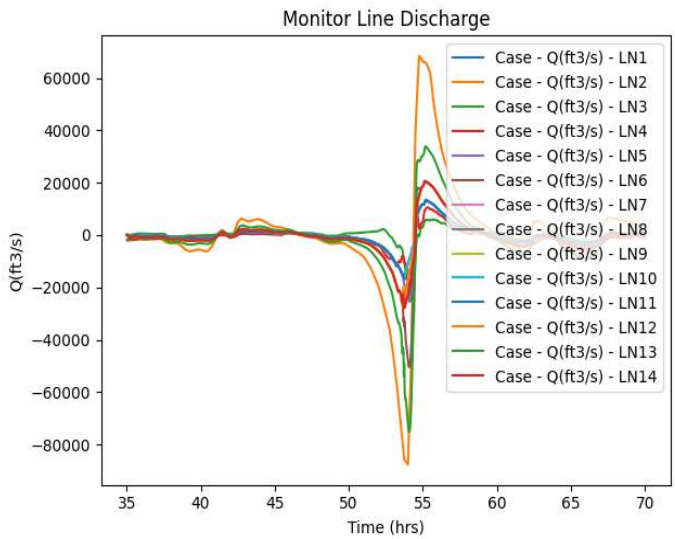
SRH-2D version: 3.6.5

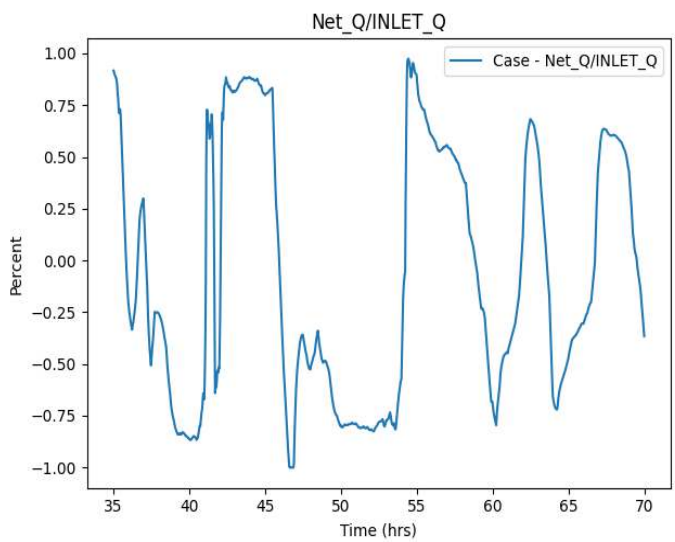
Dataset	Minimum	Maximum
Water_Elev_ft	-0.0595661663	2.1886975765
Water_Depth_ft	-10.6745920181	32.8321304321
Vel_Mag_ft_p_s	0.0	2.9487342834
Froude	1.5359638068e-15	0.7725082636
B_Stress_lb_p_ft2	5.2725036805e-30	0.2957337499

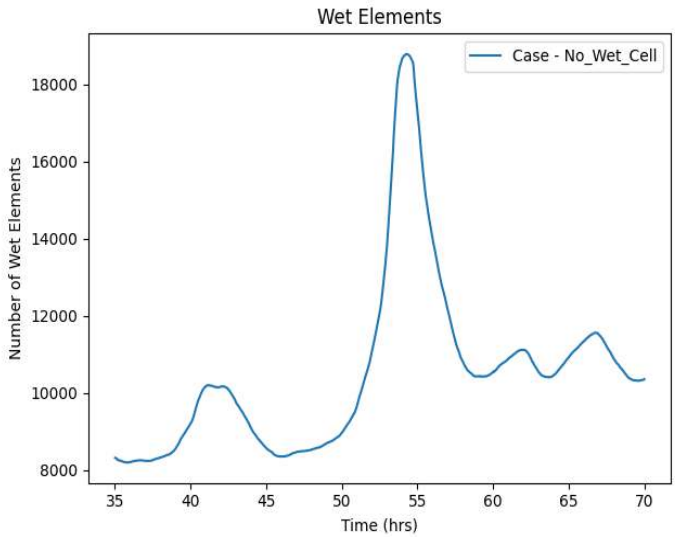
- Simulation name: Proposed 100-yr Coastal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 35.0
    - Time step (seconds): 1.0
    - End time (hours): 70.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 0.0
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)
  - Mesh used: "Proposed Mesh"
  - Boundary condition coverage used: "Coastal 100-yr BC"

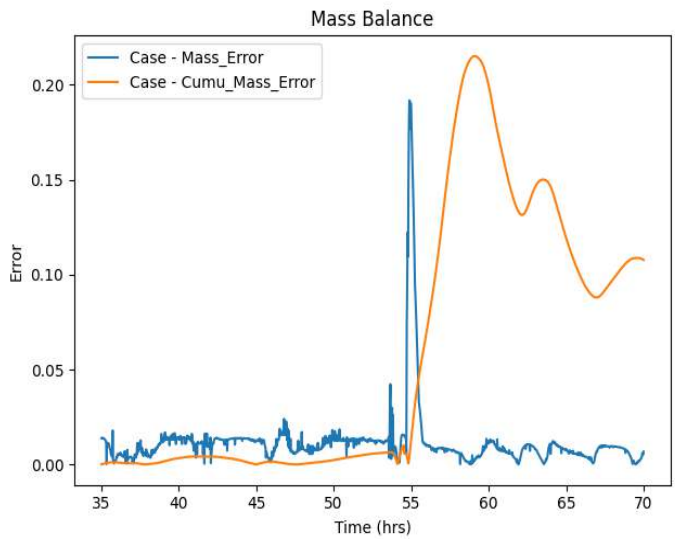
- Obstructions coverage used: None
- Materials coverage used: "Proposed Materials"
- Monitor coverage used: "Monitor Coastal"
- Solution plots











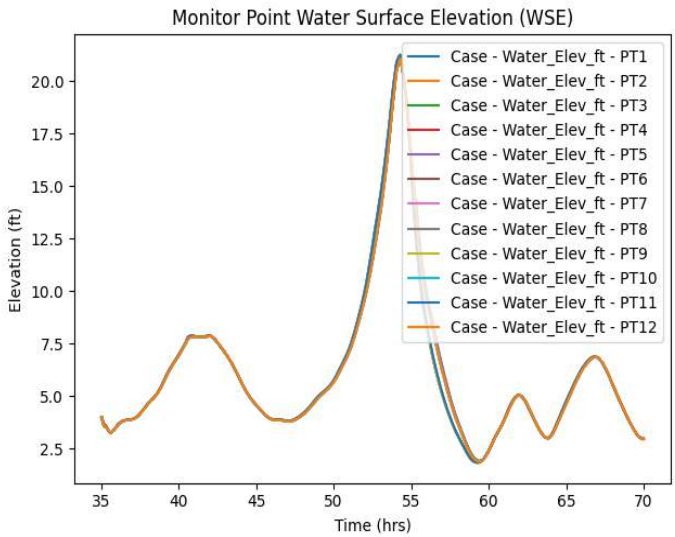
- CPU time (hours): 1.212
- Results:

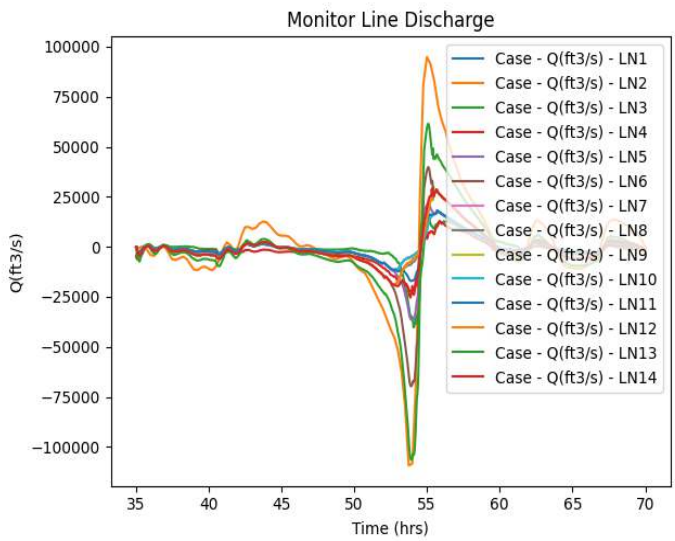
SRH-2D version: 3.6.5

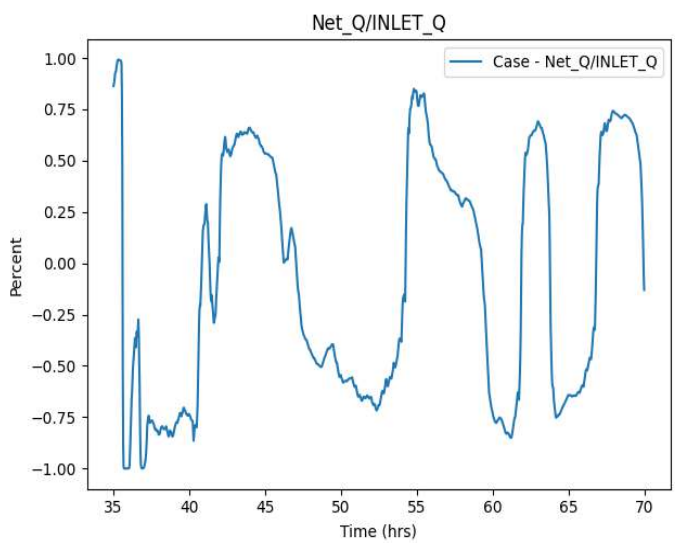
Dataset	Minimum	Maximum
Water_Elev_ft	-2.3614132404	45.1682395935
Water_Elev+Pressure_ft	-2.3614132404	45.1682395935
Water_Depth_ft	-11.7550897598	47.1545677185
Vel_Mag_ft_p_s	0.0	12.0506601334
Froude	0.0	5.2055034637
B_Stress_lb_p_ft2	0.0	35.673248291

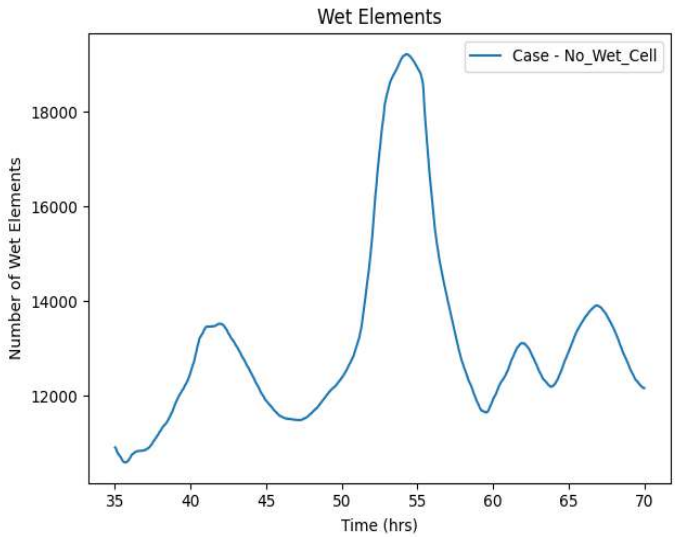
- Simulation name: Proposed 100-yr RSLR Coastal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 35.0
    - Time step (seconds): 1.0
    - End time (hours): 70.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 4.0
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

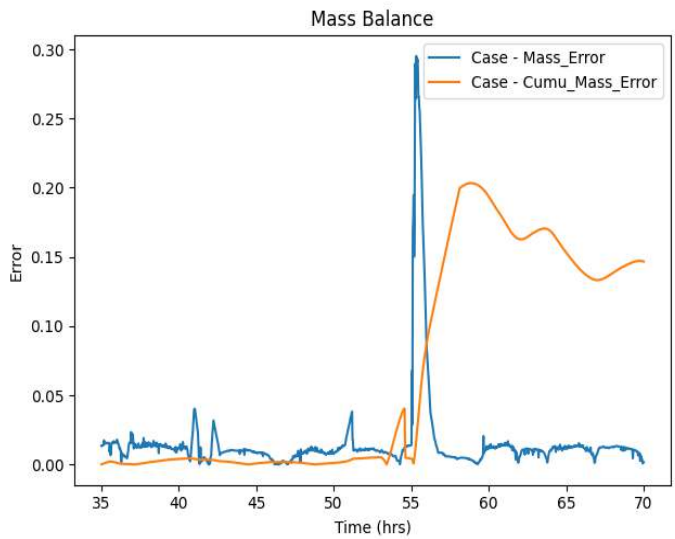
- Mesh used: "Proposed Mesh"
- Boundary condition coverage used: "Coastal 100-yr RSLR BC"
- Obstructions coverage used: None
- Materials coverage used: "Proposed Materials"
- Monitor coverage used: "Monitor Coastal"
- Solution plots











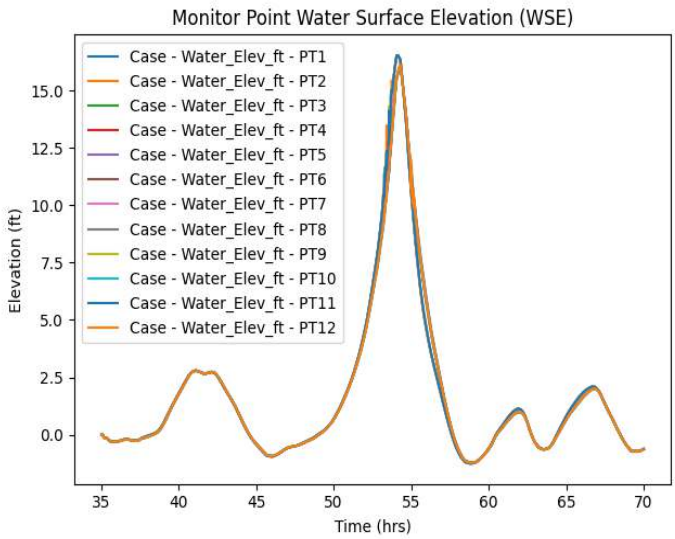
- CPU time (hours): 1.245
- Results:

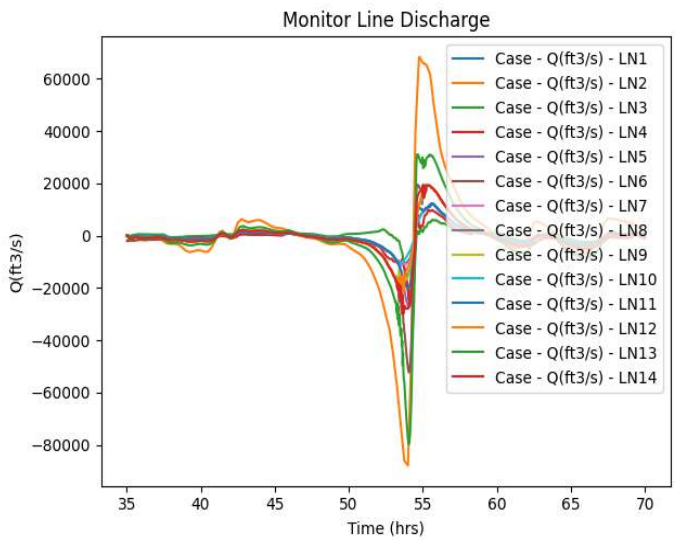
SRH-2D version: 3.6.5

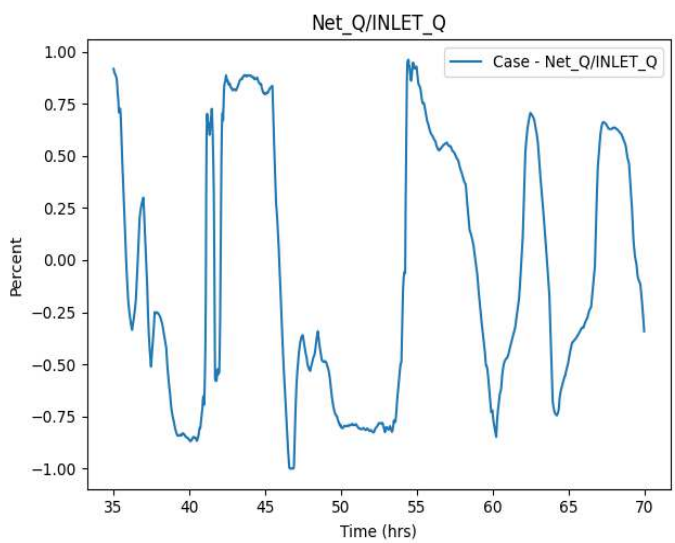
Dataset	Minimum	Maximum
Water_Elev_ft	0.2313700467	45.0220413208
Water_Elev+Pressure_ft	0.2313700467	45.0220413208
Water_Depth_ft	-11.8293485641	52.0909042358
Vel_Mag_ft_p_s	0.0	20.890920639
Froude	0.0	5.4797787666
B_Stress_lb_p_ft2	0.0	126.4559860229

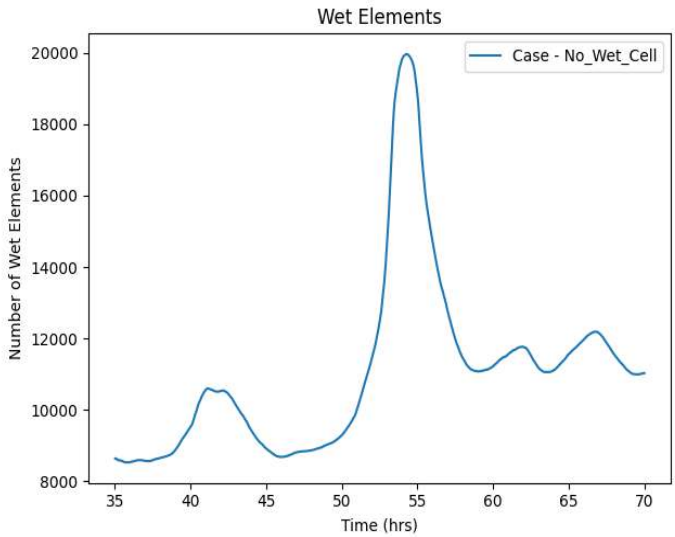
- Simulation name: Existing 100-yr Coastal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 35.0
    - Time step (seconds): 1.0
    - End time (hours): 70.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 0.0
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

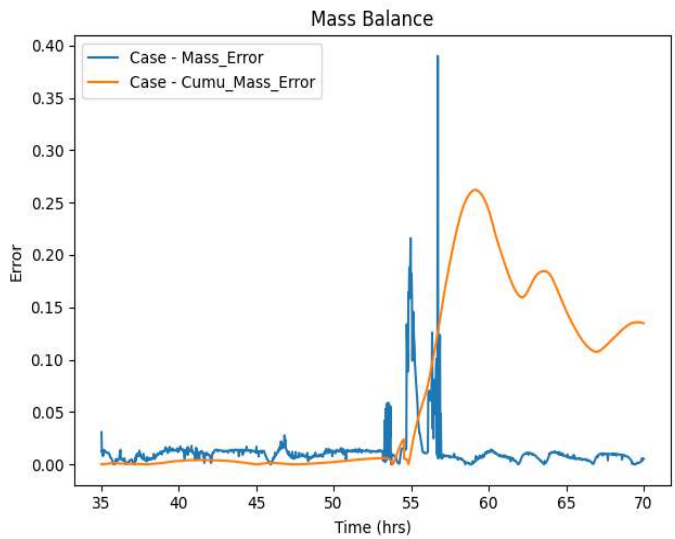
- Mesh used: "Existing Mesh"
- Boundary condition coverage used: "Coastal 100-yr BC Existing"
- Obstructions coverage used: None
- Materials coverage used: "Existing Materials"
- Monitor coverage used: "Monitor Coastal"
- Solution plots











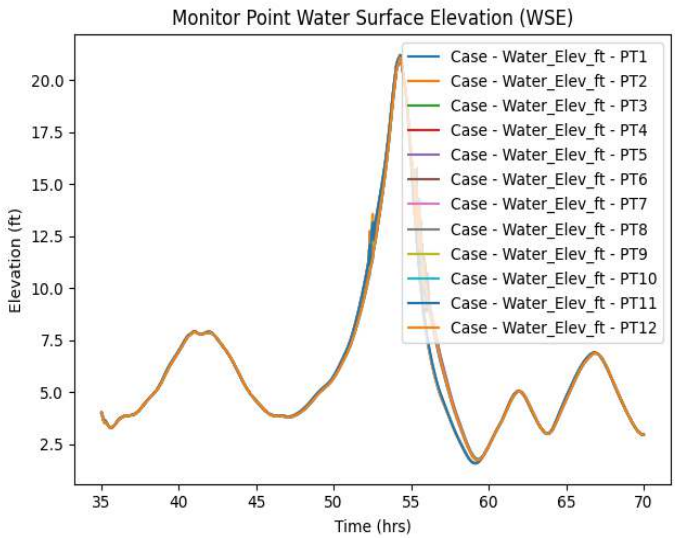
- CPU time (hours): 1.276
- Results:

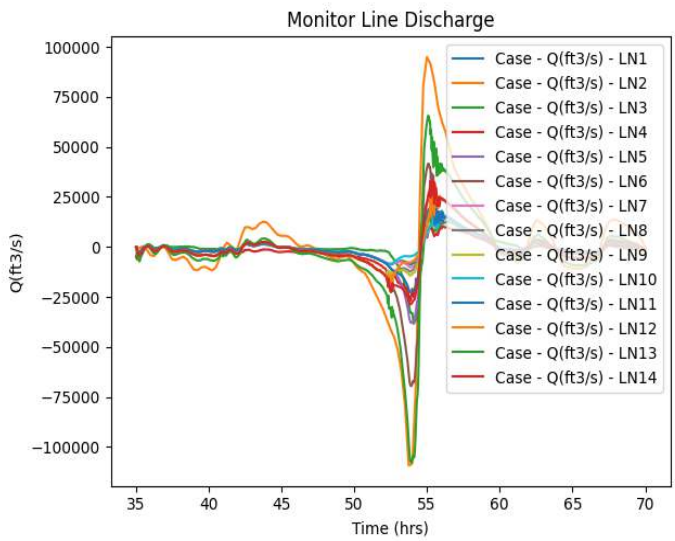
SRH-2D version: 3.6.5

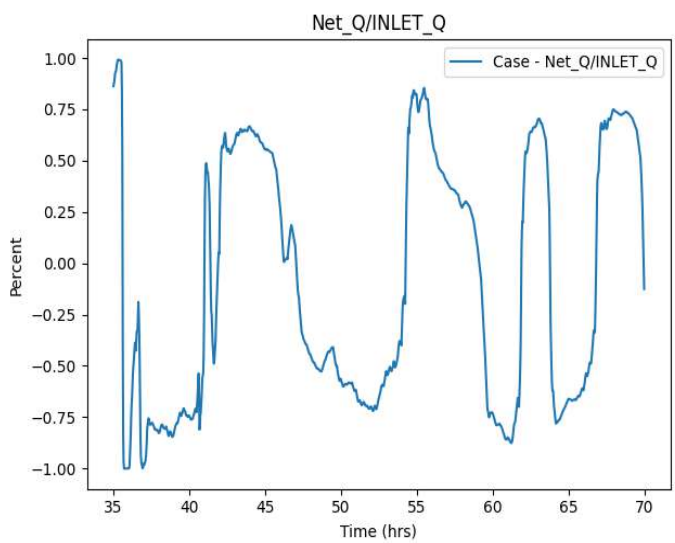
Dataset	Minimum	Maximum
Water_Elev_ft	-7.4769592285	45.157535553
Water_Elev+Pressure_ft	-7.4769592285	45.157535553
Water_Depth_ft	-11.9294137955	46.7416381836
Vel_Mag_ft_p_s	0.0	12.916762352
Froude	0.0	8.6809835434
B_Stress_lb_p_ft2	0.0	17.6593875885

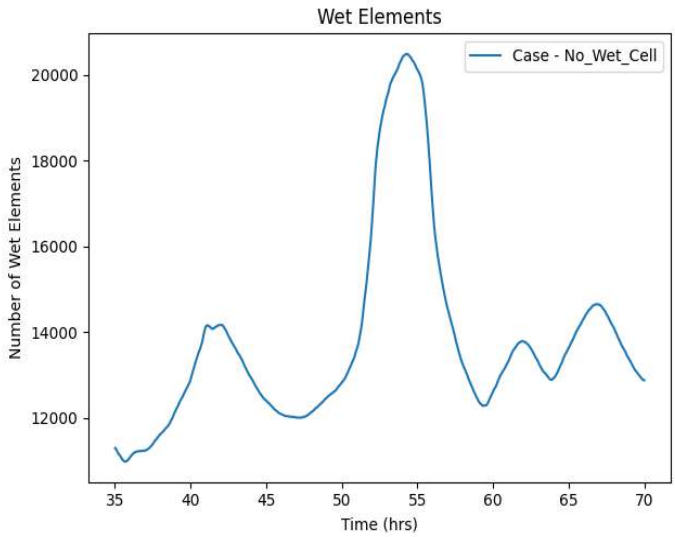
- Simulation name: Existing 100-yr RSLR Coastal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 35.0
    - Time step (seconds): 1.0
    - End time (hours): 70.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 4.0
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

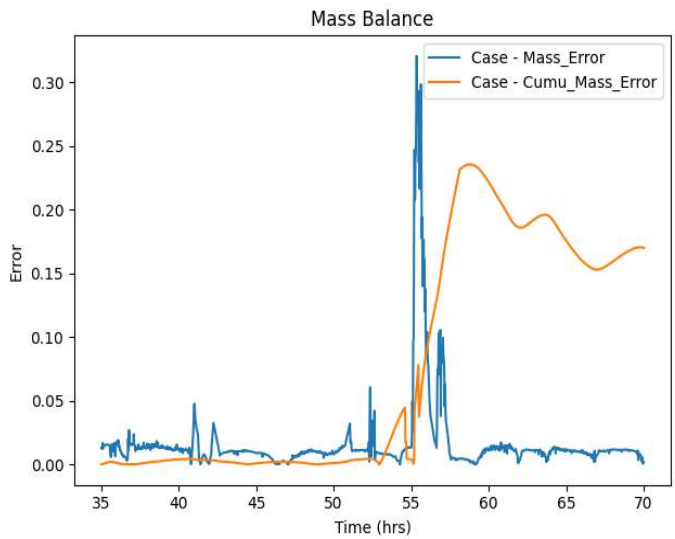
- Mesh used: "Existing Mesh"
- Boundary condition coverage used: "Coastal 100-yr RSLR BC Existing"
- Obstructions coverage used: None
- Materials coverage used: "Existing Materials"
- Monitor coverage used: "Monitor Coastal"
- Solution plots











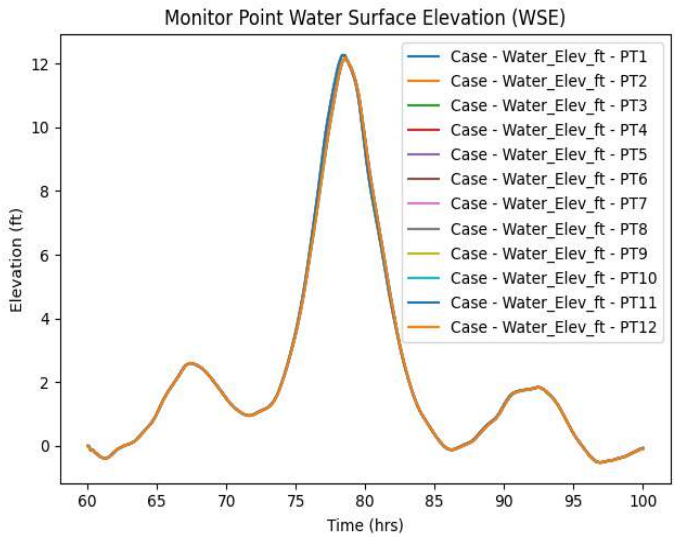
- CPU time (hours): 1.312
- Results:

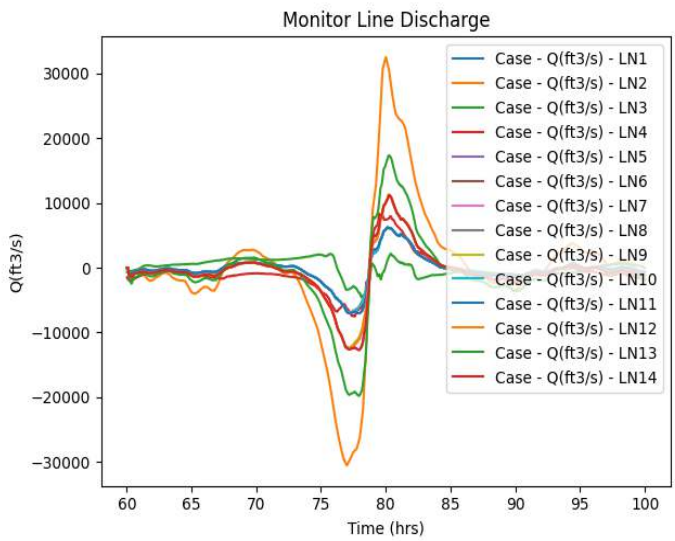
SRH-2D version: 3.6.5

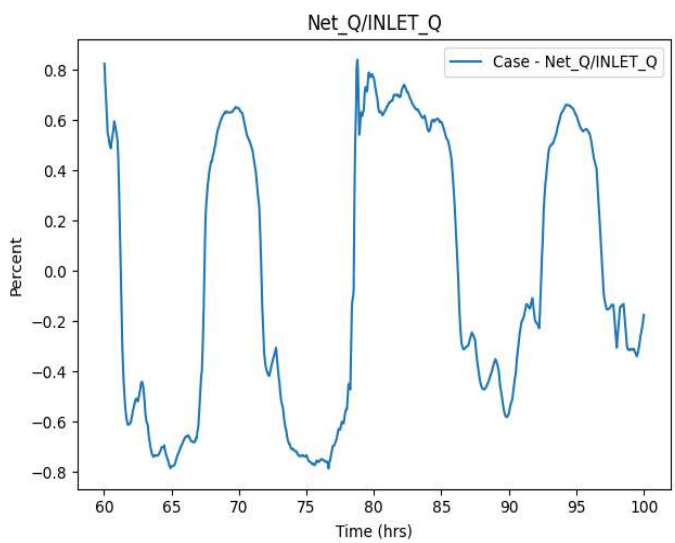
Dataset	Minimum	Maximum
Water_Elev_ft	-7.4133710861	45.0114135742
Water_Elev+Pressure_ft	-7.4133710861	45.0114135742
Water_Depth_ft	-11.6274089813	51.7038192749
Vel_Mag_ft_p_s	0.0	22.4982395172
Froude	0.0	4.9369182587
B_Stress_lb_p_ft2	0.0	144.0204772949

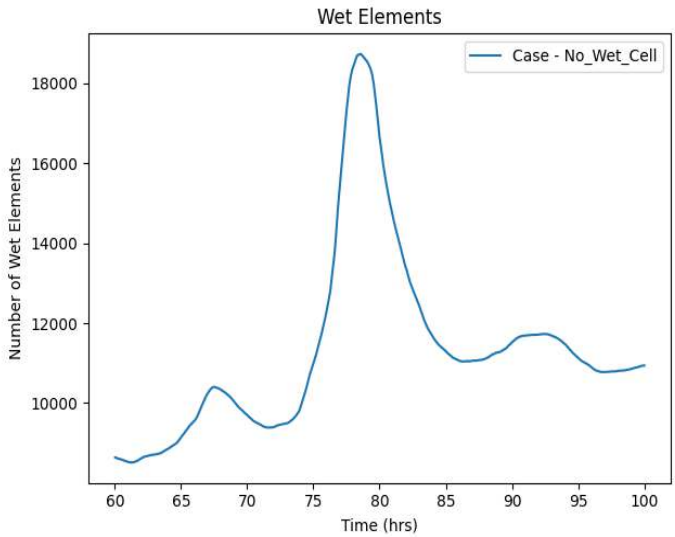
- Simulation name: Existing 50-yr Coastal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 60.0
    - Time step (seconds): 1.0
    - End time (hours): 100.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 0.0
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

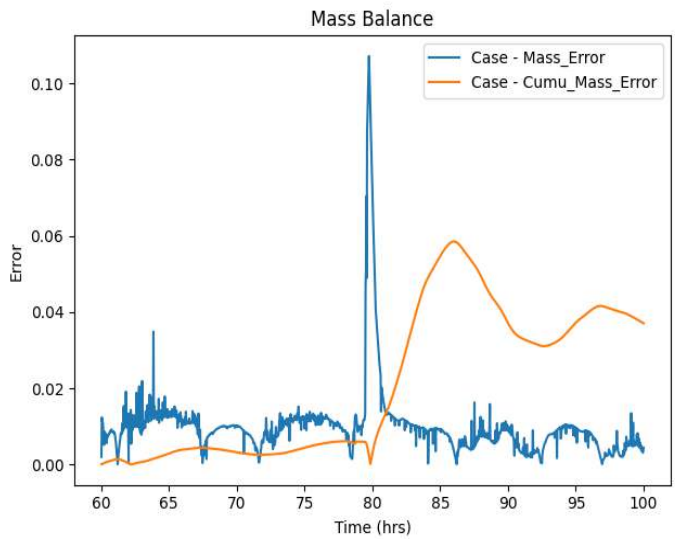
- Mesh used: "Existing Mesh"
- Boundary condition coverage used: "Coastal 50-yr BC Existing"
- Obstructions coverage used: None
- Materials coverage used: "Existing Materials"
- Monitor coverage used: "Monitor Coastal"
- Solution plots











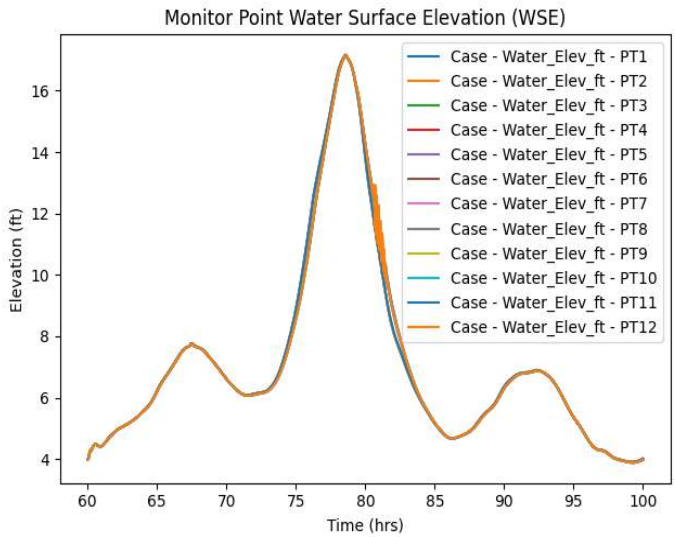
- CPU time (hours): 1.448
- Results:

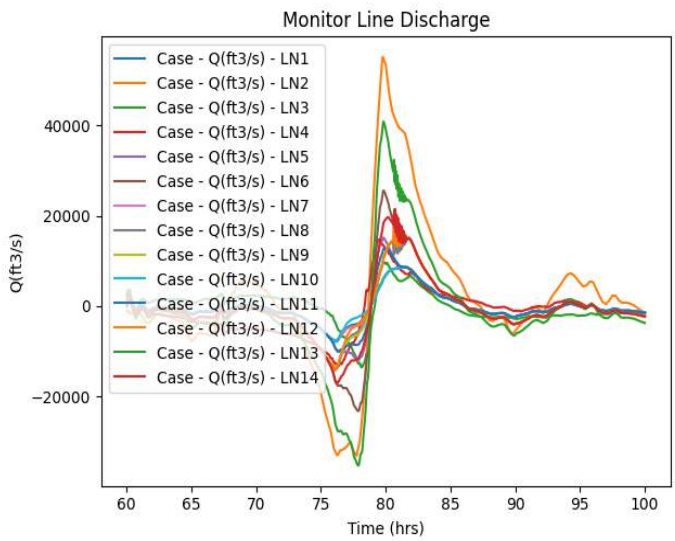
SRH-2D version: 3.6.5

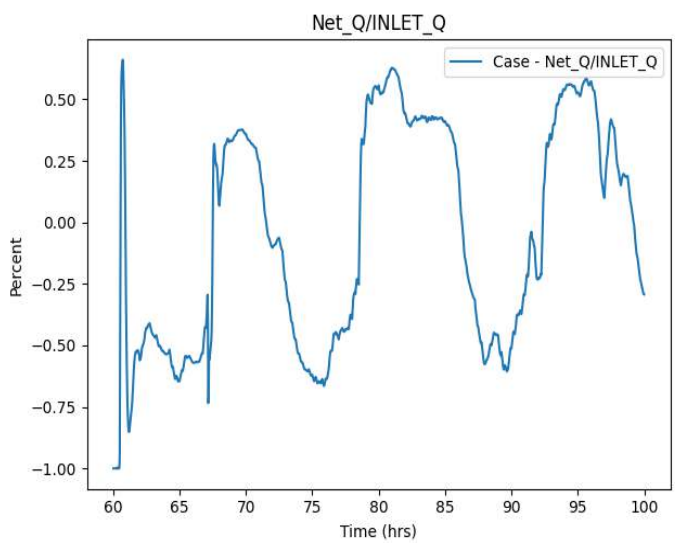
Dataset	Minimum	Maximum
Water_Elev_ft	-0.828982532	45.107635498
Water_Elev+Pressure_ft	-0.828982532	45.107635498
Water_Depth_ft	-11.5937213898	42.8532333374
Vel_Mag_ft_p_s	0.0	6.599858284
Froude	0.0	3.5982937813
B_Stress_lb_p_ft2	0.0	2.1687762737

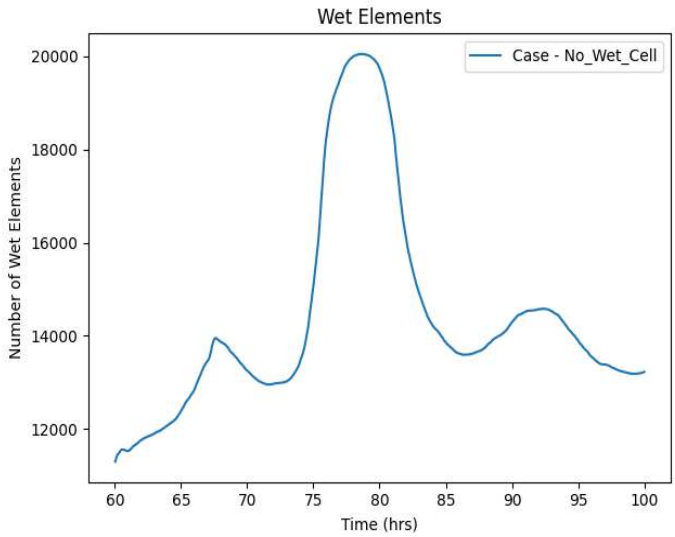
- Simulation name: Existing 50-yr RSLR Coastal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 60.0
    - Time step (seconds): 1.0
    - End time (hours): 100.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 4.0
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

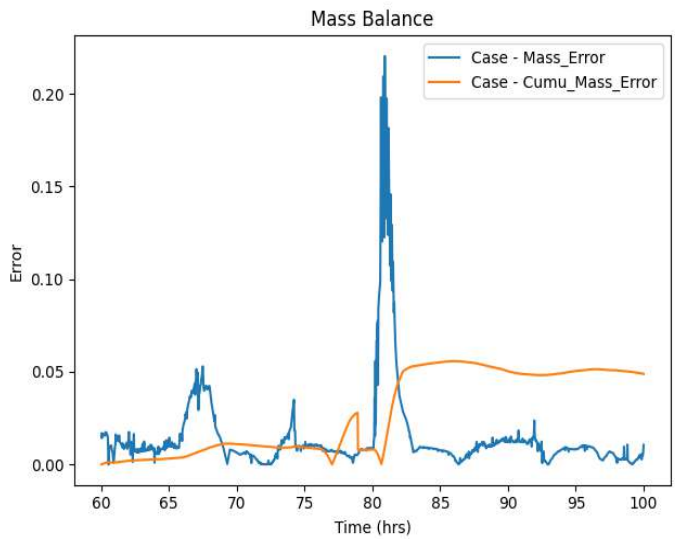
- Mesh used: "Existing Mesh"
- Boundary condition coverage used: "Coastal 50-yr RSLR BC Existing"
- Obstructions coverage used: None
- Materials coverage used: "Existing Materials"
- Monitor coverage used: "Monitor Coastal"
- Solution plots











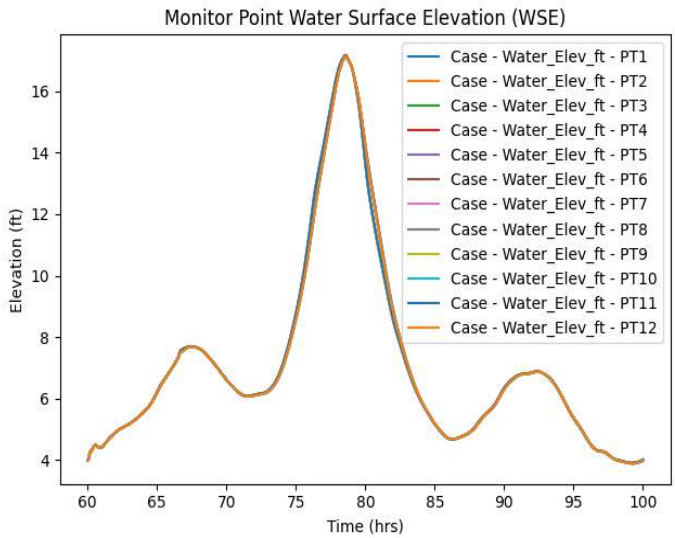
- CPU time (hours): 1.48
- Results:

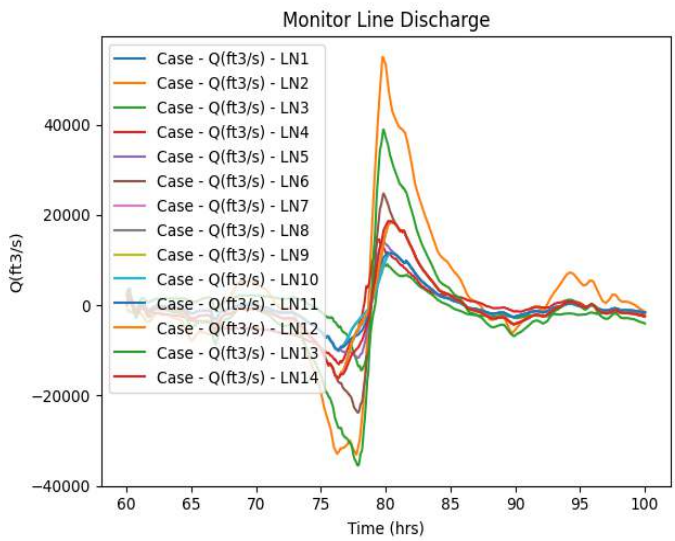
SRH-2D version: 3.6.5

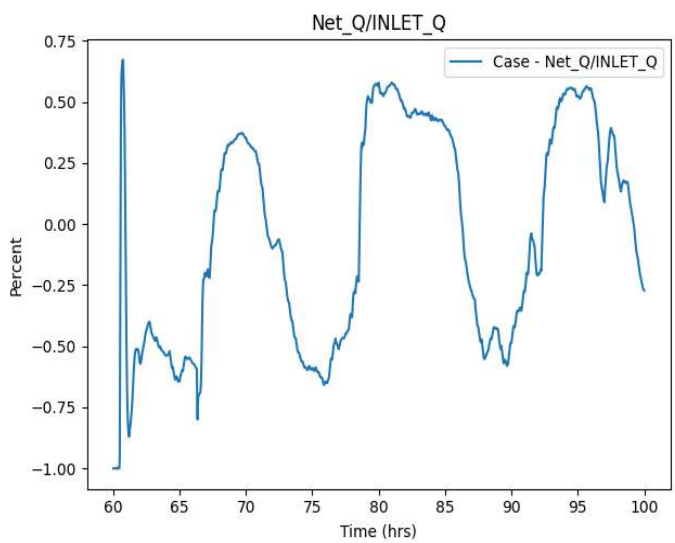
Dataset	Minimum	Maximum
Water_Elev_ft	3.8313398361	45.0808029175
Water_Elev+Pressure_ft	3.8313398361	45.0808029175
Water_Depth_ft	-11.7299633026	47.8104972839
Vel_Mag_ft_p_s	0.0	10.978966713
Froude	0.0	4.0217227936
B_Stress_lb_p_ft2	0.0	18.100484848

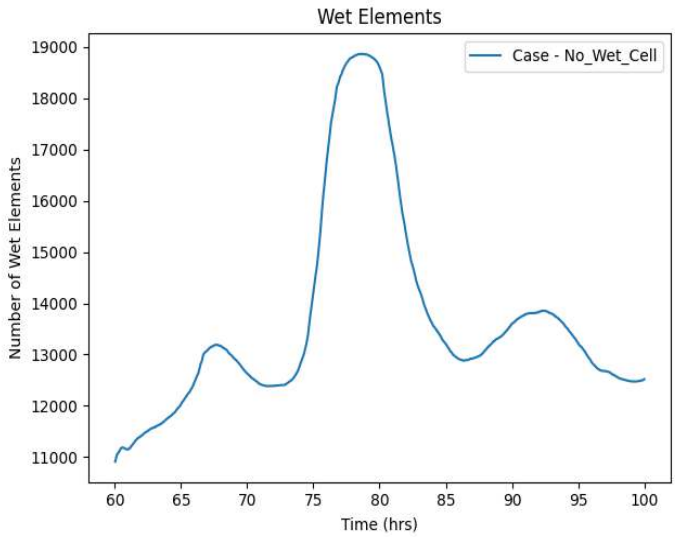
- Simulation name: Proposed 50-yr RSLR Coastal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 60.0
    - Time step (seconds): 1.0
    - End time (hours): 100.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 4.0
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

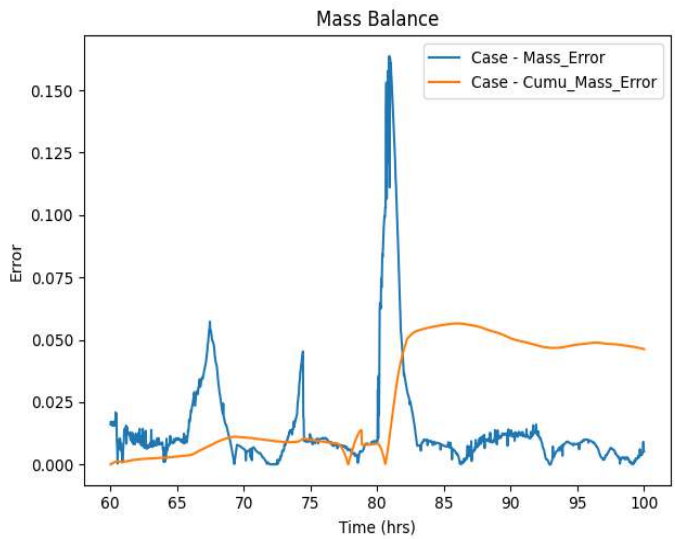
- Mesh used: "Proposed Mesh"
- Boundary condition coverage used: "Coastal 50-yr RSLR BC"
- Obstructions coverage used: None
- Materials coverage used: "Proposed Materials"
- Monitor coverage used: "Monitor Coastal"
- Solution plots











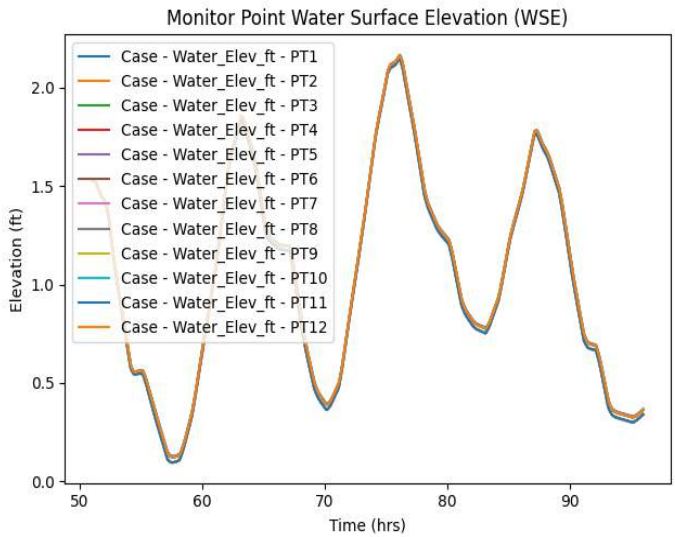
- CPU time (hours): 1.419
- Results:

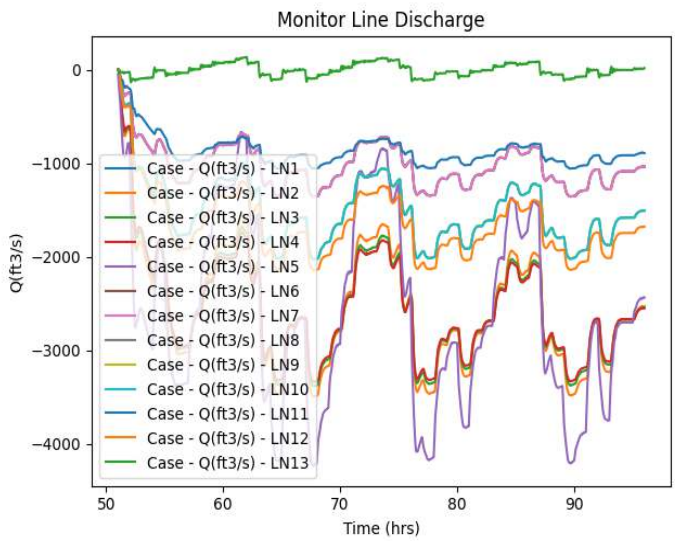
SRH-2D version: 3.6.5

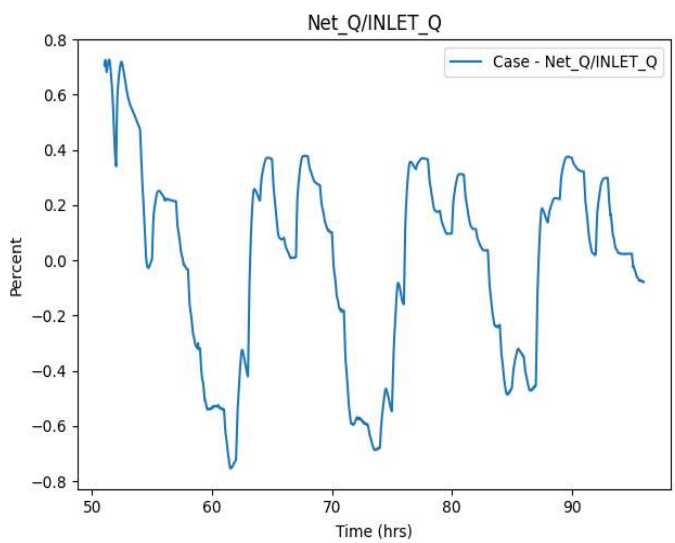
Dataset	Minimum	Maximum
Water_Elev_ft	3.8143177032	45.0913314819
Water_Elev+Pressure_ft	3.8143177032	45.0913314819
Water_Depth_ft	-11.8229589462	48.1882705688
Vel_Mag_ft_p_s	0.0	8.1700725555
Froude	0.0	4.63012743
B_Stress_lb_p_ft2	0.0	21.6417980194

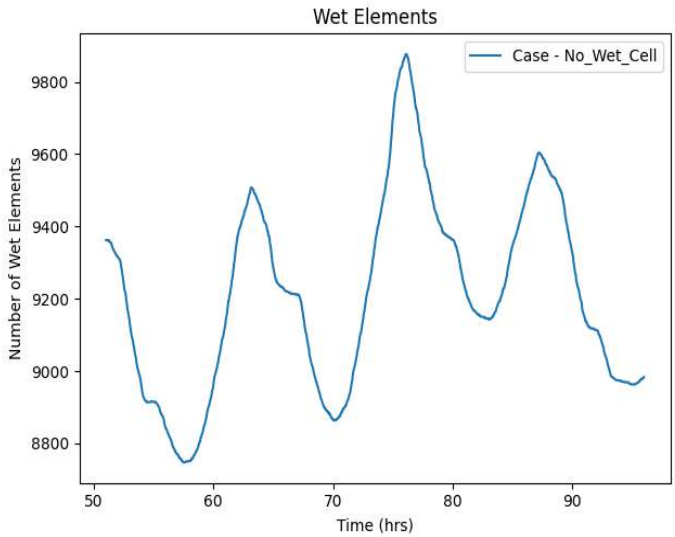
- Simulation name: Sens Analysis + channel n
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 51.0
    - Time step (seconds): 1.0
    - End time (hours): 96.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 1.53
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

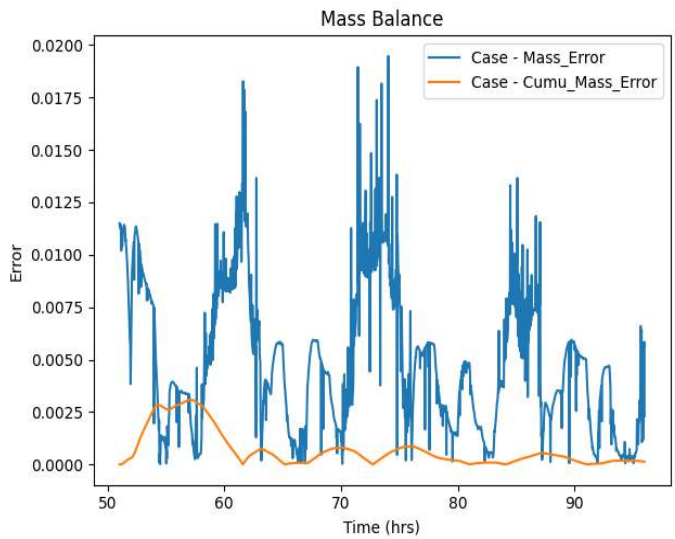
- Mesh used: "Existing Mesh"
- Boundary condition coverage used: "Woods Hole Tidal 50-yr"
- Obstructions coverage used: None
- Materials coverage used: "Existing Materials + 0.00875 channel n"
- Monitor coverage used: "Monitor Riverine"
- Solution plots











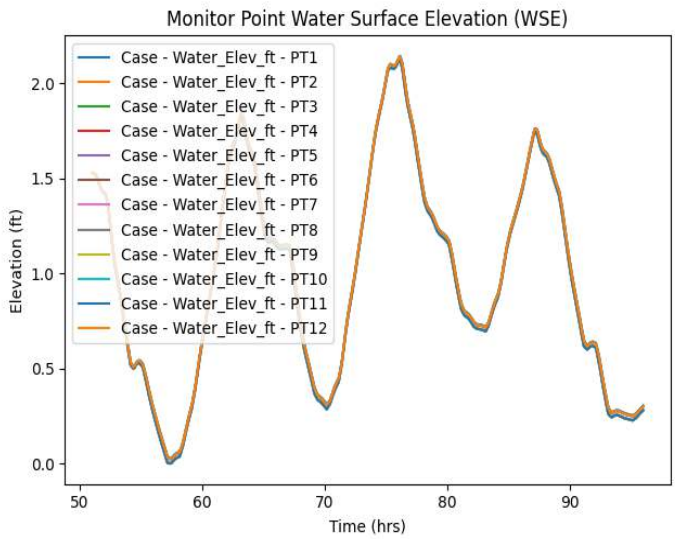
- CPU time (hours): 1.592
- Results:

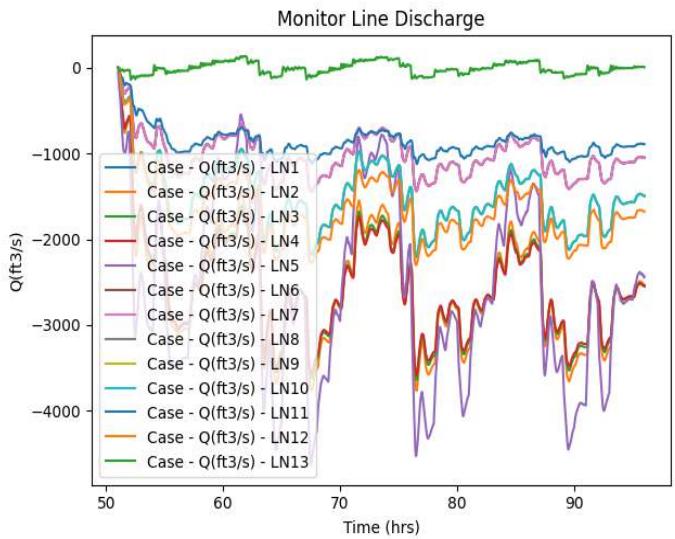
SRH-2D version: 3.6.5

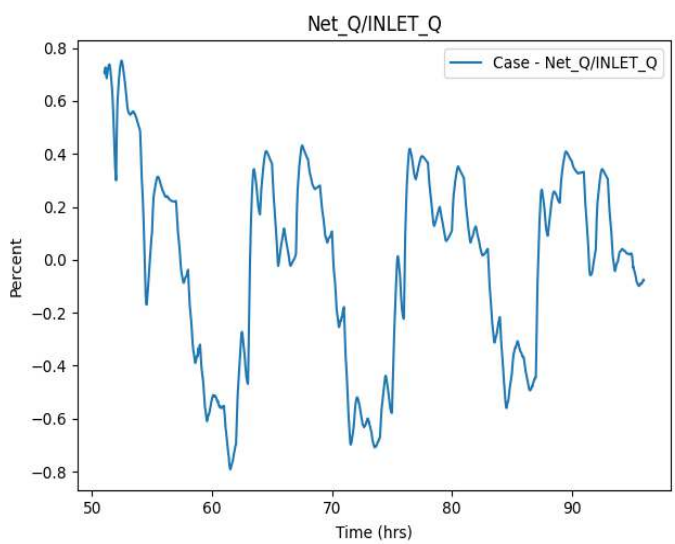
Dataset	Minimum	Maximum
Water_Elev_ft	-0.0585637353	2.2537317276
Water_Depth_ft	-10.5934829712	32.8621177673
Vel_Mag_ft_p_s	0.0	2.3618869781
Froude	1.5359638068e-15	1.1219526529
B_Stress_lb_p_ft2	5.2725036805e-30	0.4158380032

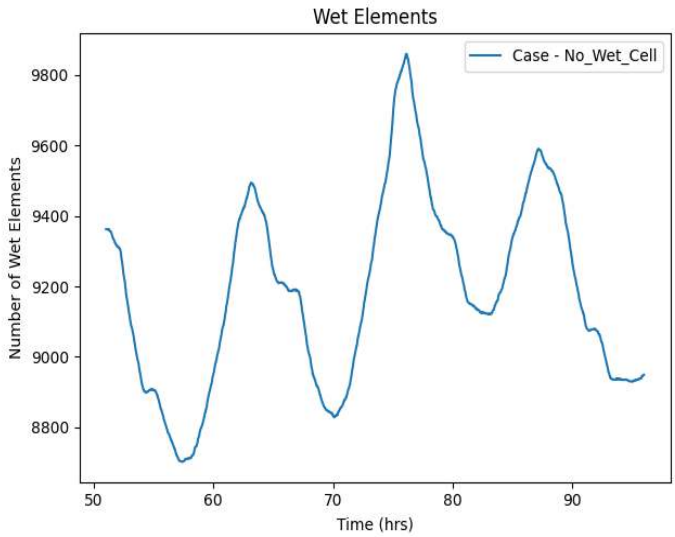
- Simulation name: Sens Analysis - channel n
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 51.0
    - Time step (seconds): 1.0
    - End time (hours): 96.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 1.53
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)
  - Mesh used: "Existing Mesh"
  - Boundary condition coverage used: "Woods Hole Tidal 50-yr"

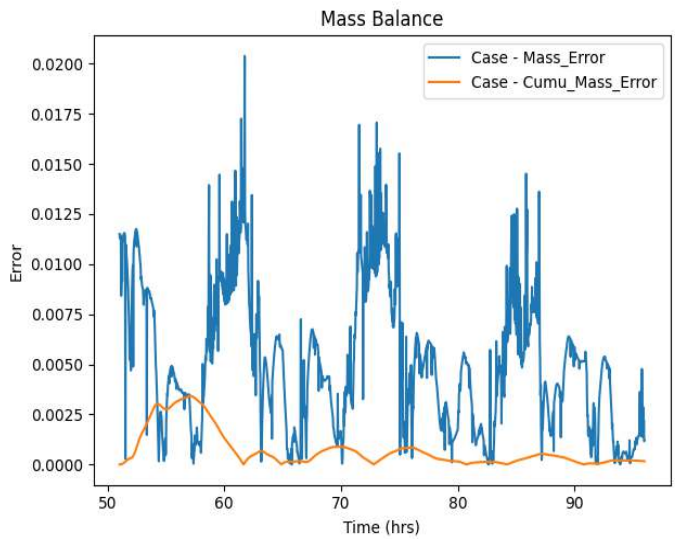
- Obstructions coverage used: None
- Materials coverage used: "Existing Materials - 0.00875 channel n"
- Monitor coverage used: "Monitor Riverine"
- Solution plots











- CPU time (hours): 1.571
- Results:

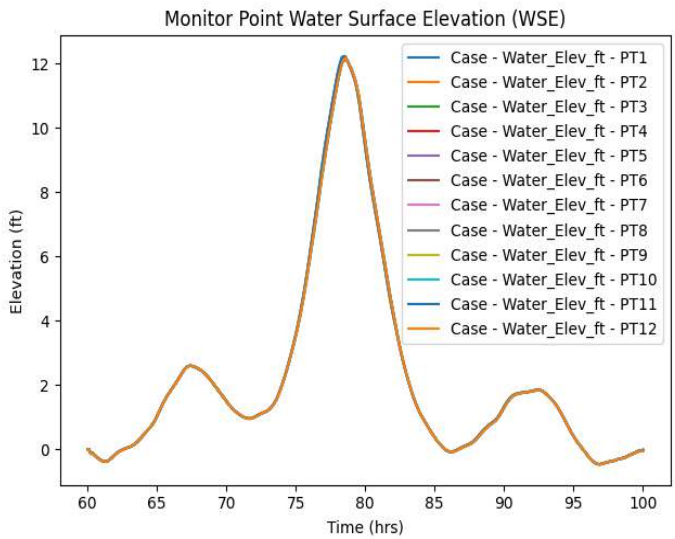
SRH-2D version: 3.6.5

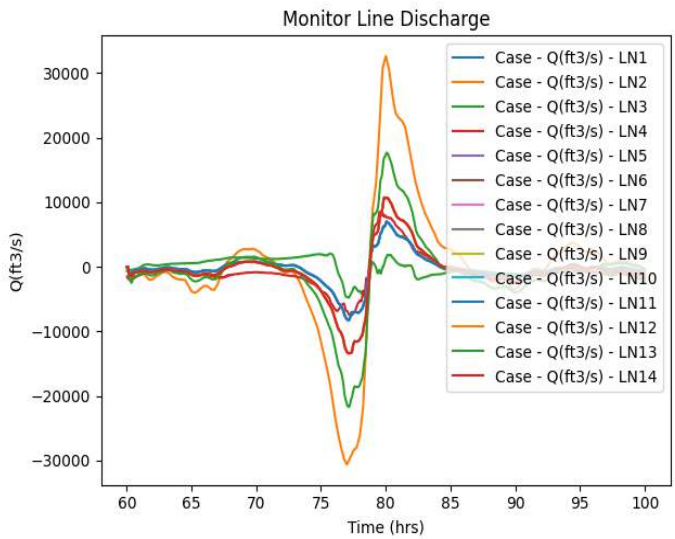
Dataset	Minimum	Maximum
Water_Elev_ft	-0.0597371459	2.2100114822
Water_Depth_ft	-10.6856460571	32.8347892761
Vel_Mag_ft_p_s	0.0	3.6096558571
Froude	1.5359638068e-15	1.2279913425
B_Stress_lb_p_ft2	5.2725036805e-30	0.2442889959

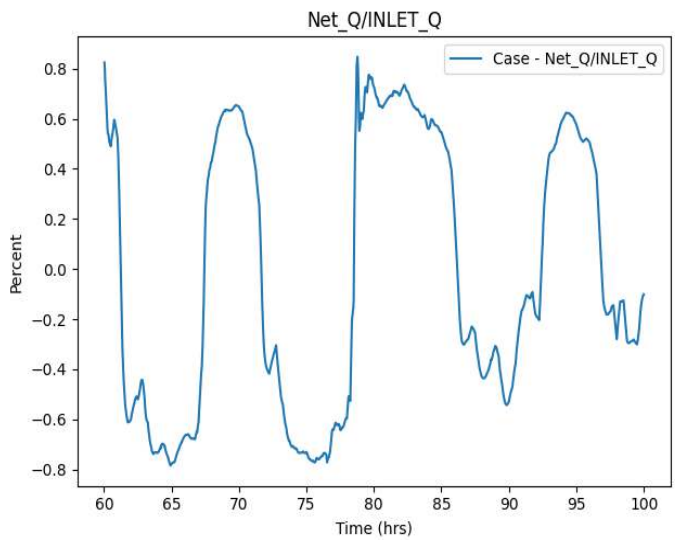
- Simulation name: Proposed 50-yr Coastal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 60.0
    - Time step (seconds): 1.0
    - End time (hours): 100.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 0.0
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

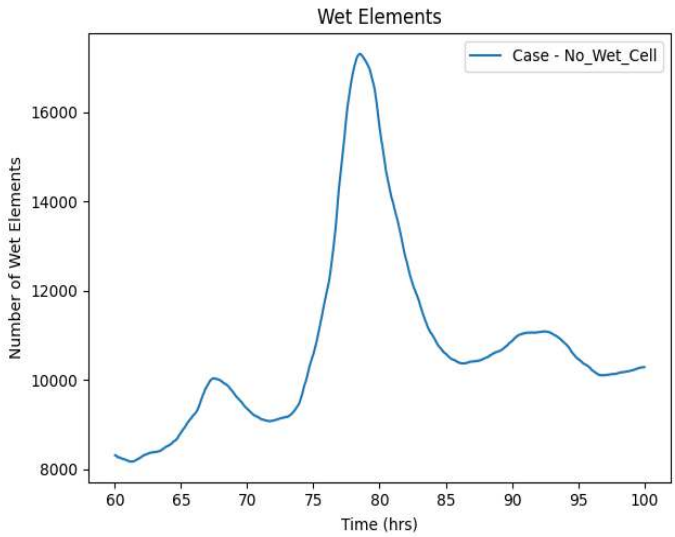
  - Mesh used: "Proposed Mesh"
  - Boundary condition coverage used: "Coastal 50-yr BC"

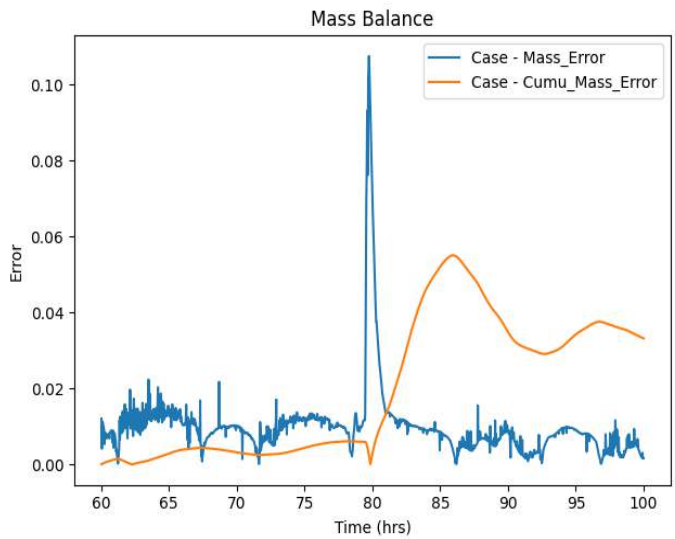
- Obstructions coverage used: None
- Materials coverage used: "Proposed Materials"
- Monitor coverage used: "Monitor Coastal"
- Solution plots











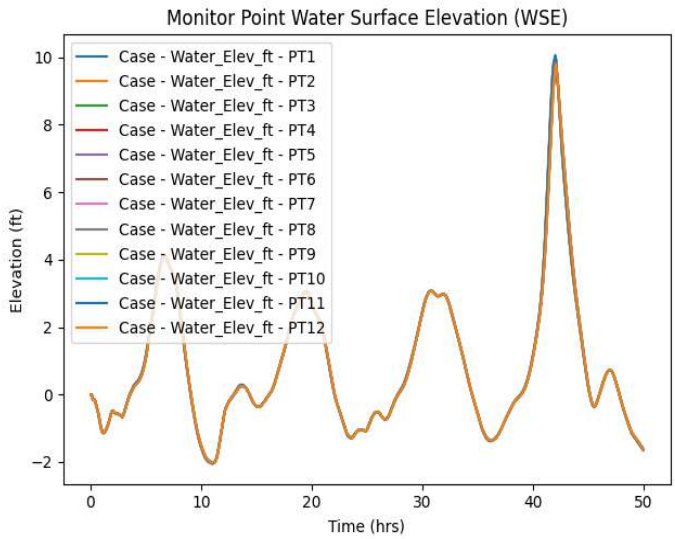
- CPU time (hours): 1.377
- Results:

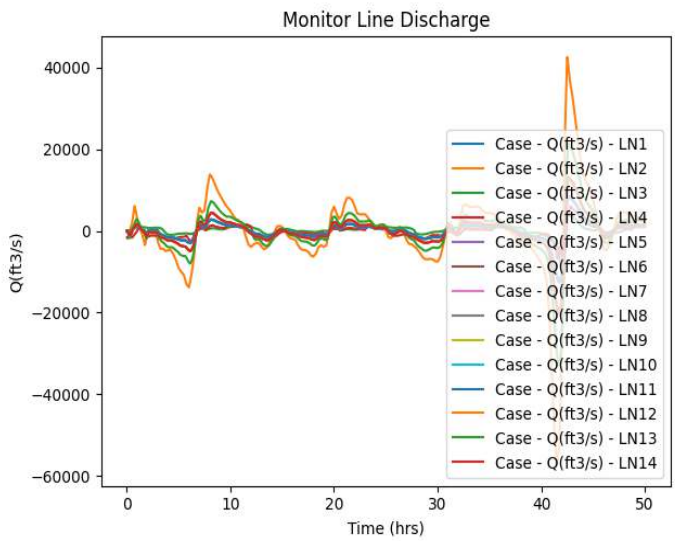
SRH-2D version: 3.6.5

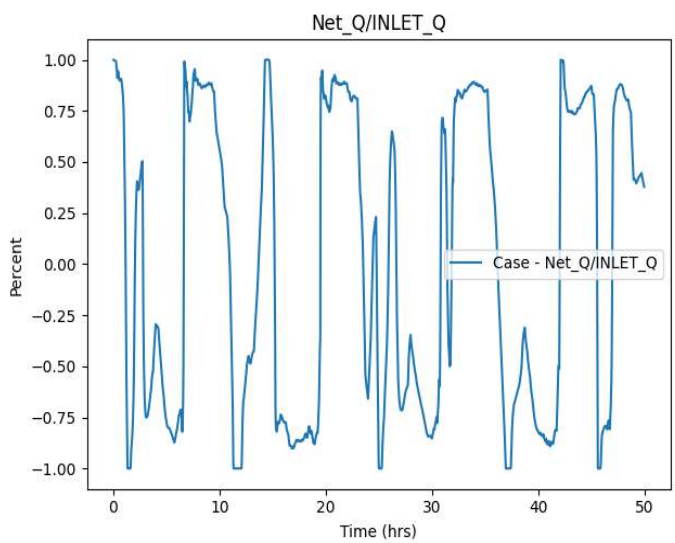
Dataset	Minimum	Maximum
Water_Elev_ft	-0.8178185225	45.1181106567
Water_Elev+Pressure_ft	-0.8178185225	45.1181106567
Water_Depth_ft	-11.5791759491	43.2288208008
Vel_Mag_ft_p_s	0.0	6.4524354935
Froude	0.0	3.9679243565
B_Stress_lb_p_ft2	0.0	2.4749884605

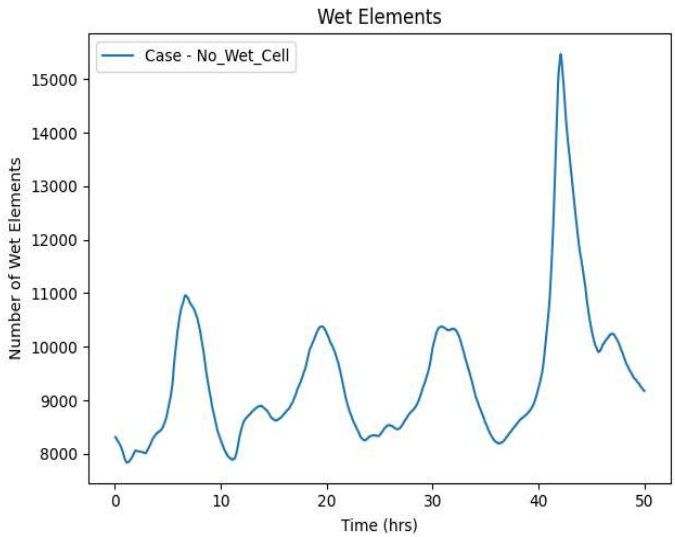
- Simulation name: Proposed 25-yr Coastal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 0.0
    - Time step (seconds): 1.0
    - End time (hours): 50.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 0.0
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

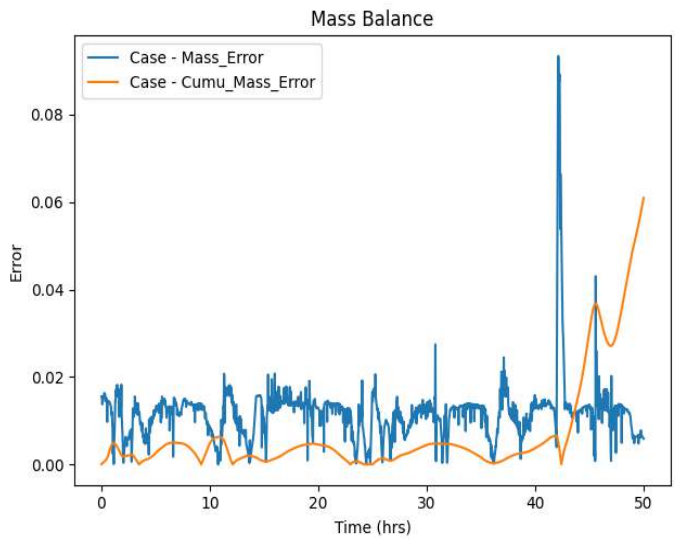
- Mesh used: "Proposed Mesh"
- Boundary condition coverage used: "Coastal 25-yr BC"
- Obstructions coverage used: None
- Materials coverage used: "Proposed Materials"
- Monitor coverage used: "Monitor Coastal"
- Solution plots











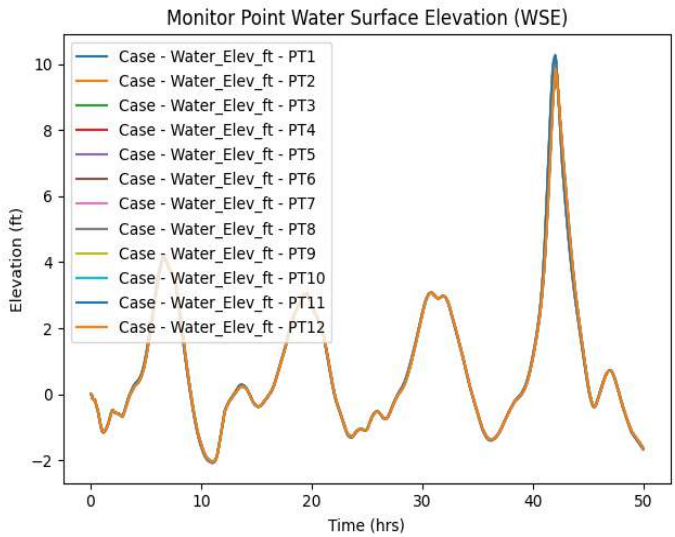
- CPU time (hours): 1.637
- Results:

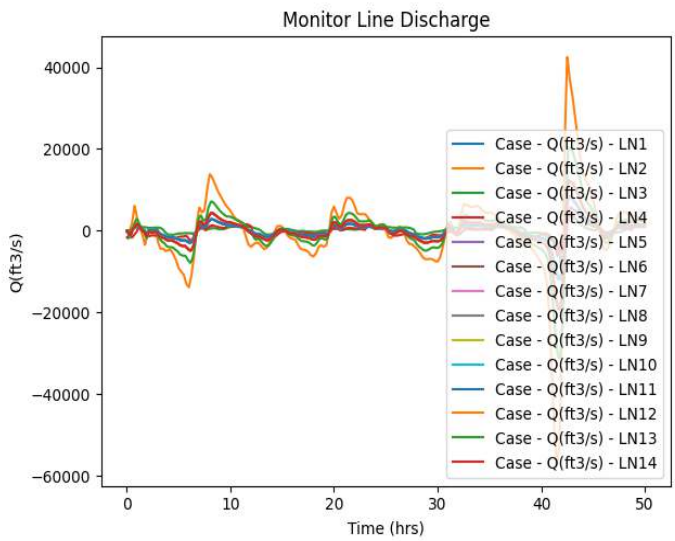
SRH-2D version: 3.6.5

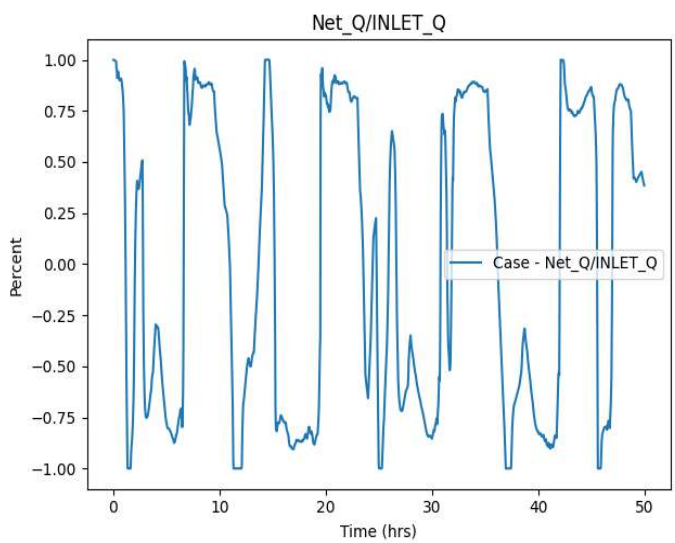
Dataset	Minimum	Maximum
Water_Elev_ft	-2.3777253628	39.9614715576
Water_Elev+Pressure_ft	-2.3777253628	39.9614715576
Water_Depth_ft	-11.7096271515	40.6516075134
Vel_Mag_ft_p_s	0.0	10.2670612335
Froude	0.0	3.1720962524
B_Stress_lb_p_ft2	0.0	2.356849432

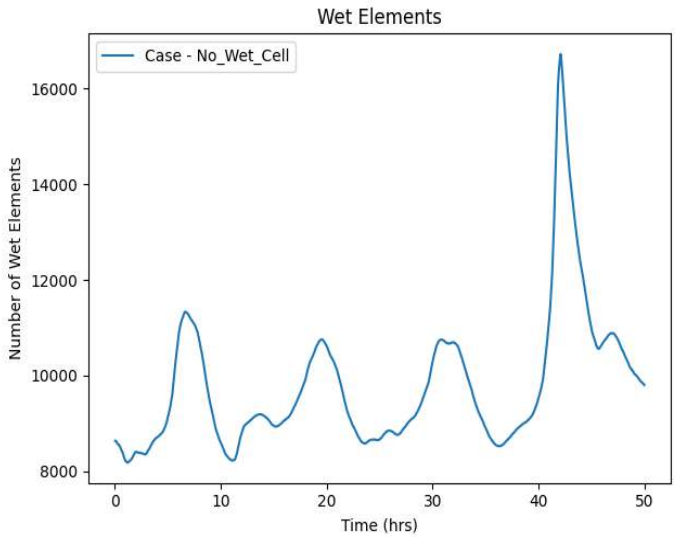
- Simulation name: Existing 25-yr Coastal
  - Summary of model controls
    - Simulation type: Flow
    - Start time (hours): 0.0
    - Time step (seconds): 1.0
    - End time (hours): 50.0
    - Initial condition: Initial Water Surface Elevation
    - Initial value: 0.0
    - Turbulence model: Parabolic
    - Turbulence parameter: 0.7
    - Unsteady output: True
    - Pressure dataset: NA
    - Output method: Specified Frequency
    - Output frequency: 15.0 (Minutes)

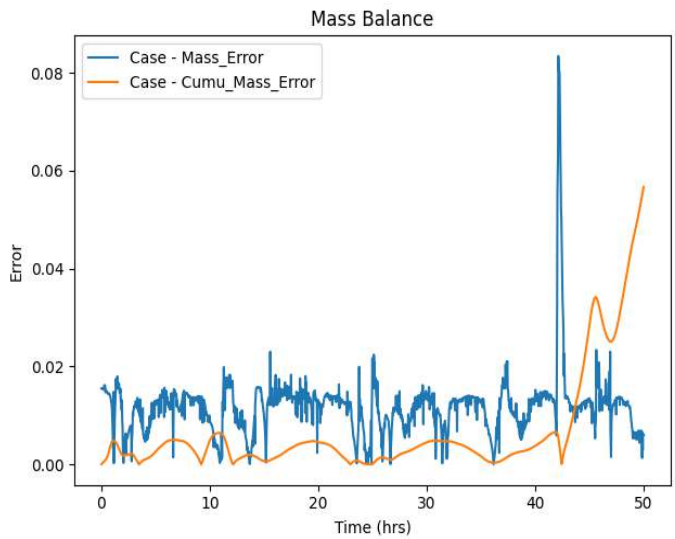
- Mesh used: "Existing Mesh"
- Boundary condition coverage used: "Coastal 25-yr BC"
- Obstructions coverage used: None
- Materials coverage used: "Existing Materials"
- Monitor coverage used: "Monitor Coastal"
- Solution plots











- CPU time (hours): 1.728
- Results:

SRH-2D version: 3.6.5

Dataset	Minimum	Maximum
Water_Elev_ft	-2.3984062672	39.9440727234
Water_Depth_ft	-12.7482023239	40.2412338257
Vel_Mag_ft_p_s	0.0	10.6578073502
Froude	0.0	3.5679168701
B_Stress_lb_p_ft2	0.0	2.7950983047

Appendix E. Bridge Hydraulic Loading Sheets

MW_B1-100 YR

Substructure

Summary (factored Loads)

	Lateral Loads
Wave Force Load Factor, γ_W:	1.75
Pile Cap Forces	
Pile Cap Factored Forces (lbs):	11,712.6
Pile Cap Resultant Elevation (ft.):	6.4
Pile Forces	
Single Pile Factored Force (lbs):	55,084.5
Single Pile Resultant Elevation (ft.):	-4.7
Total Pile Reduction Applied (sum for all piles):	5.07
Total Loading on all piles in a single pier (kip):	279.4
Total Force on Main Pier (kips):	291.1
	Lateral
Crest Elevation of Maximum Wave Height (ft):	21.4
Crest Elevation of Significant Wave Height (ft):	19.0

Superstructure

Summary (factored Loads)

Lateral Loads	
Wave Force Load Factor, γ_W:	1.75
Design Case 1	
Quasi-Static Vertical Force (kip/ft):	40.4
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	40.4
Horizontal Force (kip/ft):	2.1
Moment (kip-ft/ft):	2210.7
Design Case 2	
Quasi-Static Vertical Force (kip/ft):	15.5
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	15.5
Horizontal Force (kip/ft):	5.5
Moment (kip-ft/ft):	426.7
Design Case 3a	
Vertical Force (kip/ft):	2.1
Horizontal Force (kip/ft):	0.8
Design Case 3b	
Vertical Force (kip/ft):	0.8
Horizontal Force (kip/ft):	2.1

Inputs

1a. Lateral Wave Input

Datum:	NAVD
Hs (ft):	4.32
Tp (sec):	3.26
Water Surface Elevation	16
Bottom Elevation (ft, Datum):	-14.75
Current Speed (ft/s):	7.24

1b. Longitudinal Wave Input

Hs (ft):	0.1
Tp (sec):	3
Current Speed (ft/s):	0.1

2. Structure Input

Critical Structure:	Yes
Span Type:	Girder
Coefficients Selection:	AASHTO Type III
gW (pcf):	64.3
W (ft):	77.2
W* (ft):	72.7
db (ft):	4.79
dg (ft):	2.75
r (ft)	4.5
Pile Cap Height (ft):	4.354166667
Deck Elevation (ft, Datum):	14.04
Pedestal (ft):	0.75
%AIR:	100
Cd, super structure	2.5

Calculation Time Stamp: 5/22/2024 15:57

Lateral

Wsub (ft):	4.5

Longitudinal

Wsub (ft):	77.2
Cd, pile	2
Cm, pile	2.5
A, pile	12.56637061
V, pile	12.56637061
n	6
s	13.5

Program Files Location: C:\Users\msadowski\Downloads\MW Matlab\Bridge Loading\Function_Files

MW_B1-500 YR

Substructure

Summary (factored Loads)

	Lateral Loads
Wave Force Load Factor, γ_W:	1.75
Pile Cap Forces	
Pile Cap Factored Forces (lbs):	17,906.4
Pile Cap Resultant Elevation (ft.):	6.4
Pile Forces	
Single Pile Factored Force (lbs):	114,737.7
Single Pile Resultant Elevation (ft.):	-4.9
Total Pile Reduction Applied (sum for all piles):	5.08
Total Loading on all piles in a single pier (kip):	582.9
Total Force on Main Pier (kips):	600.8
	Lateral
Crest Elevation of Maximum Wave Height (ft):	24.4
Crest Elevation of Significant Wave Height (ft):	21.7

Superstructure

Summary (factored Loads)

Lateral Loads	
Wave Force Load Factor, γ_W:	1.75
Design Case 1	
Quasi-Static Vertical Force (kip/ft):	49.0
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	49.0
Horizontal Force (kip/ft):	5.1
Moment (kip-ft/ft):	2665.8
Design Case 2	
Quasi-Static Vertical Force (kip/ft):	18.7
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	18.7
Horizontal Force (kip/ft):	8.2
Moment (kip-ft/ft):	417.8
Design Case 3a	
Vertical Force (kip/ft):	2.5
Horizontal Force (kip/ft):	2.0
Design Case 3b	
Vertical Force (kip/ft):	1.0
Horizontal Force (kip/ft):	3.3

Inputs

1a. Lateral Wave Input

Datum:	NAVD
Hs (ft):	5.43
Tp (sec):	3.58
Water Surface Elevation	17.87
Bottom Elevation (ft, Datum):	-14.75
Current Speed (ft/s):	10.55

1b. Longitudinal Wave Input

Hs (ft):	0.1
Tp (sec):	3
Current Speed (ft/s):	0.1

2. Structure Input

Critical Structure:	Yes
Span Type:	Girder
Coefficients Selection:	AASHTO Type III
gW (pcf):	64.3
W (ft):	77.2
W* (ft):	72.7
db (ft):	4.79
dg (ft):	2.75
r (ft)	4.5
Pile Cap Height (ft):	4.354166667
Deck Elevation (ft, Datum):	14.04
Pedestal (ft):	0.75
%AIR:	100
Cd, super structure	2.5

Calculation Time Stamp: 5/22/2024 15:50

Lateral

Wsub (ft):	4.5

Longitudinal

Wsub (ft):	77.2
Cd, pile	2
Cm, pile	2.5
A, pile	12.56637061
V, pile	12.56637061
n	6
s	13.5

Program Files Location: C:\Users\msadowski\Downloads\MW Matlab\Bridge Loading\Function_Files

MW_B1-100 YR RSLR

Substructure

Summary (factored Loads)

	Lateral Loads
Wave Force Load Factor, γ_W:	1.75
Pile Cap Forces	
Pile Cap Factored Forces (lbs):	13,013.4
Pile Cap Resultant Elevation (ft.):	6.4
Pile Forces	
Single Pile Factored Force (lbs):	63,088.0
Single Pile Resultant Elevation (ft.):	-4.9
Total Pile Reduction Applied (sum for all piles):	4.66
Total Loading on all piles in a single pier (kip):	294.0
Total Force on Main Pier (kips):	307.1
	Lateral
Crest Elevation of Maximum Wave Height (ft):	27.9
Crest Elevation of Significant Wave Height (ft):	24.8

Superstructure

Summary (factored Loads)

Lateral Loads	
Wave Force Load Factor, γ_W:	1.75
Design Case 1	
Quasi-Static Vertical Force (kip/ft):	66.1
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	66.1
Horizontal Force (kip/ft):	3.1
Moment (kip-ft/ft):	3564.0
Design Case 2	
Quasi-Static Vertical Force (kip/ft):	22.2
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	22.2
Horizontal Force (kip/ft):	5.8
Moment (kip-ft/ft):	404.4
Design Case 3a	
Vertical Force (kip/ft):	3.4
Horizontal Force (kip/ft):	1.3
Design Case 3b	
Vertical Force (kip/ft):	1.1
Horizontal Force (kip/ft):	2.3

Inputs

1a. Lateral Wave Input

Datum:	NAVD
Hs (ft):	5.46
Tp (sec):	3.81
Water Surface Elevation	21
Bottom Elevation (ft, Datum):	-14.75
Current Speed (ft/s):	7.52

1b. Longitudinal Wave Input

Hs (ft):	0.1
Tp (sec):	3
Current Speed (ft/s):	0.1

2. Structure Input

Critical Structure:	Yes
Span Type:	Girder
Coefficients Selection:	AASHTO Type III
gW (pcf):	64.3
W (ft):	77.2
W* (ft):	72.7
db (ft):	4.79
dg (ft):	2.75
r (ft)	4.5
Pile Cap Height (ft):	4.354166667
Deck Elevation (ft, Datum):	14.04
Pedestal (ft):	0.75
%AIR:	100
Cd, super structure	2.5

Calculation Time Stamp: 5/22/2024 15:49

Lateral

Wsub (ft):	4.5

Longitudinal

Wsub (ft):	77.2
Cd, pile	2
Cm, pile	2.5
A, pile	12.56637061
V, pile	12.56637061
n	6
s	13.5

Program Files Location: C:\Users\msadowski\Downloads\MW Matlab\Bridge Loading\Function_Files

MW_B1-500 YR RSLR

Substructure

Summary (factored Loads)

	Lateral Loads
Wave Force Load Factor, γ_W:	1.75
Pile Cap Forces	
Pile Cap Factored Forces (lbs):	15,293.7
Pile Cap Resultant Elevation (ft.):	6.4
Pile Forces	
Single Pile Factored Force (lbs):	76,006.4
Single Pile Resultant Elevation (ft.):	-4.9
Total Pile Reduction Applied (sum for all piles):	4.33
Total Loading on all piles in a single pier (kip):	329.1
Total Force on Main Pier (kips):	344.4
	Lateral
Crest Elevation of Maximum Wave Height (ft):	31.8
Crest Elevation of Significant Wave Height (ft):	28.0

Superstructure

Summary (factored Loads)

Lateral Loads	
Wave Force Load Factor, γ_W:	1.75
Design Case 1	
Quasi-Static Vertical Force (kip/ft):	73.9
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	73.9
Horizontal Force (kip/ft):	3.5
Moment (kip-ft/ft):	3957.0
Design Case 2	
Quasi-Static Vertical Force (kip/ft):	20.7
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	20.7
Horizontal Force (kip/ft):	6.1
Moment (kip-ft/ft):	315.5
Design Case 3a	
Vertical Force (kip/ft):	3.8
Horizontal Force (kip/ft):	1.4
Design Case 3b	
Vertical Force (kip/ft):	1.1
Horizontal Force (kip/ft):	2.5

Inputs

1a. Lateral Wave Input

Datum:	NAVD
Hs (ft):	6.82
Tp (sec):	4.18
Water Surface Elevation	23.2
Bottom Elevation (ft, Datum):	-14.75
Current Speed (ft/s):	7.86

1b. Longitudinal Wave Input

Hs (ft):	0.1
Tp (sec):	3
Current Speed (ft/s):	0.1

2. Structure Input

Critical Structure:	Yes
Span Type:	Girder
Coefficients Selection:	AASHTO Type III
gW (pcf):	64.3
W (ft):	77.2
W* (ft):	72.7
db (ft):	4.79
dg (ft):	2.75
r (ft)	4.5
Pile Cap Height (ft):	4.354166667
Deck Elevation (ft, Datum):	14.04
Pedestal (ft):	0.75
%AIR:	100
Cd, super structure	2.5

Calculation Time Stamp: 5/22/2024 15:50

Lateral

Wsub (ft):	4.5

Longitudinal

Wsub (ft):	77.2
Cd, pile	2
Cm, pile	2.5
A, pile	12.56637061
V, pile	12.56637061
n	6
s	13.5

Program Files Location: C:\Users\msadowski\Downloads\MW Matlab\Bridge Loading\Function_Files

MW_B2_3-100 YR

Substructure

Summary (factored Loads)

	Lateral Loads
Wave Force Load Factor, γ_W:	1.75
Pile Cap Forces	
Pile Cap Factored Forces (lbs):	12,858.8
Pile Cap Resultant Elevation (ft.):	5.9
Pile Forces	
Single Pile Factored Force (lbs):	38,716.8
Single Pile Resultant Elevation (ft.):	-4.1
Total Pile Reduction Applied (sum for all piles):	4.93
Total Loading on all piles in a single pier (kip):	190.9
Total Force on Main Pier (kips):	203.8
	Lateral
Crest Elevation of Maximum Wave Height (ft):	21.4
Crest Elevation of Significant Wave Height (ft):	19.0

Superstructure

Summary (factored Loads)

Lateral Loads	
Wave Force Load Factor, γ_W:	1.75
Design Case 1	
Quasi-Static Vertical Force (kip/ft):	39.6
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	39.6
Horizontal Force (kip/ft):	1.9
Moment (kip-ft/ft):	2166.4
Design Case 2	
Quasi-Static Vertical Force (kip/ft):	15.5
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	15.5
Horizontal Force (kip/ft):	5.2
Moment (kip-ft/ft):	428.4
Design Case 3a	
Vertical Force (kip/ft):	2.0
Horizontal Force (kip/ft):	0.7
Design Case 3b	
Vertical Force (kip/ft):	0.8
Horizontal Force (kip/ft):	2.0

Inputs

1a. Lateral Wave Input

Datum:	NAVD
Hs (ft):	4.32
Tp (sec):	3.26
Water Surface Elevation	16
Bottom Elevation (ft, Datum):	-12.13
Current Speed (ft/s):	6.6

1b. Longitudinal Wave Input

Hs (ft):	0.1
Tp (sec):	3
Current Speed (ft/s):	0.1

2. Structure Input

Critical Structure:	Yes
Span Type:	Girder
Coefficients Selection:	AASHTO Type III
gW (pcf):	64.3
W (ft):	77.2
W* (ft):	72.7
db (ft):	4.8
dg (ft):	2.75
r (ft)	4.5
Pile Cap Height (ft):	5.291666667
Deck Elevation (ft, Datum):	14.04
Pedestal (ft):	0.75
%AIR:	100
Cd, super structure	2.5

Calculation Time Stamp: 5/22/2024 15:52

Lateral

Wsub (ft):	4.5

Longitudinal

Wsub (ft):	77.2
Cd, pile	2
Cm, pile	2.5
A, pile	12.56637061
V, pile	12.56637061
n	6
s	13.5

Program Files Location: C:\Users\msadowski\Downloads\MW Matlab\Bridge Loading\Function_Files

MW_B2_3-500 YR

Substructure

Summary (factored Loads)

	Lateral Loads
Wave Force Load Factor, γ_W:	1.75
Pile Cap Forces	
Pile Cap Factored Forces (lbs):	20,915.4
Pile Cap Resultant Elevation (ft.):	5.9
Pile Forces	
Single Pile Factored Force (lbs):	92,819.2
Single Pile Resultant Elevation (ft.):	-4.2
Total Pile Reduction Applied (sum for all piles):	5.08
Total Loading on all piles in a single pier (kip):	471.9
Total Force on Main Pier (kips):	492.8
	Lateral
Crest Elevation of Maximum Wave Height (ft):	24.3
Crest Elevation of Significant Wave Height (ft):	21.6

Superstructure

Summary (factored Loads)

Lateral Loads	
Wave Force Load Factor, γ_W:	1.75
Design Case 1	
Quasi-Static Vertical Force (kip/ft):	47.9
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	47.9
Horizontal Force (kip/ft):	5.0
Moment (kip-ft/ft):	2608.6
Design Case 2	
Quasi-Static Vertical Force (kip/ft):	18.6
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	18.6
Horizontal Force (kip/ft):	8.1
Moment (kip-ft/ft):	420.8
Design Case 3a	
Vertical Force (kip/ft):	2.4
Horizontal Force (kip/ft):	2.0
Design Case 3b	
Vertical Force (kip/ft):	1.0
Horizontal Force (kip/ft):	3.2

Inputs

1a. Lateral Wave Input

Datum:	NAVD
Hs (ft):	5.27
Tp (sec):	3.54
Water Surface Elevation	17.89
Bottom Elevation (ft, Datum):	-12.13
Current Speed (ft/s):	10.51

1b. Longitudinal Wave Input

Hs (ft):	0.1
Tp (sec):	3
Current Speed (ft/s):	0.1

2. Structure Input

Critical Structure:	Yes
Span Type:	Girder
Coefficients Selection:	AASHTO Type III
gW (pcf):	64.3
W (ft):	77.2
W* (ft):	72.7
db (ft):	4.8
dg (ft):	2.75
r (ft)	4.5
Pile Cap Height (ft):	5.291666667
Deck Elevation (ft, Datum):	14.04
Pedestal (ft):	0.75
%AIR:	100
Cd, super structure	2.5

Calculation Time Stamp: 5/22/2024 15:54

Lateral

Wsub (ft):	4.5

Longitudinal

Wsub (ft):	77.2
Cd, pile	2
Cm, pile	2.5
A, pile	12.56637061
V, pile	12.56637061
n	6
s	13.5

Program Files Location: C:\Users\msadowski\Downloads\MW Matlab\Bridge Loading\Function_Files

MW_B2_3-100 YR RSLR

Substructure

Summary (factored Loads)

	Lateral Loads
Wave Force Load Factor, γ_W:	1.75
Pile Cap Forces	
Pile Cap Factored Forces (lbs):	13,953.2
Pile Cap Resultant Elevation (ft.):	5.9
Pile Forces	
Single Pile Factored Force (lbs):	42,635.2
Single Pile Resultant Elevation (ft.):	-4.2
Total Pile Reduction Applied (sum for all piles):	4.47
Total Loading on all piles in a single pier (kip):	190.8
Total Force on Main Pier (kips):	204.7
	Lateral
Crest Elevation of Maximum Wave Height (ft):	27.8
Crest Elevation of Significant Wave Height (ft):	24.8

Superstructure

Summary (factored Loads)

Lateral Loads	
Wave Force Load Factor, γ_W:	1.75
Design Case 1	
Quasi-Static Vertical Force (kip/ft):	65.1
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	65.1
Horizontal Force (kip/ft):	2.6
Moment (kip-ft/ft):	3507.2
Design Case 2	
Quasi-Static Vertical Force (kip/ft):	22.3
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	22.3
Horizontal Force (kip/ft):	5.3
Moment (kip-ft/ft):	409.9
Design Case 3a	
Vertical Force (kip/ft):	3.3
Horizontal Force (kip/ft):	1.1
Design Case 3b	
Vertical Force (kip/ft):	1.1
Horizontal Force (kip/ft):	2.1

Inputs

1a. Lateral Wave Input

Datum:	NAVD
Hs (ft):	5.4
Tp (sec):	3.8
Water Surface Elevation	21
Bottom Elevation (ft, Datum):	-12.13
Current Speed (ft/s):	6.67

1b. Longitudinal Wave Input

Hs (ft):	0.1
Tp (sec):	3
Current Speed (ft/s):	0.1

2. Structure Input

Critical Structure:	Yes
Span Type:	Girder
Coefficients Selection:	AASHTO Type III
gW (pcf):	64.3
W (ft):	77.2
W* (ft):	72.7
db (ft):	4.8
dg (ft):	2.75
r (ft)	4.5
Pile Cap Height (ft):	5.291666667
Deck Elevation (ft, Datum):	14.04
Pedestal (ft):	0.75
%AIR:	100
Cd, super structure	2.5

Calculation Time Stamp: 5/22/2024 15:52

Lateral

Wsub (ft):	4.5

Longitudinal

Wsub (ft):	77.2
Cd, pile	2
Cm, pile	2.5
A, pile	12.56637061
V, pile	12.56637061
n	6
s	13.5

Program Files Location: C:\Users\msadowski\Downloads\MW Matlab\Bridge Loading\Function_Files

MW_B2_3-500 YR RSLR

Substructure

Summary (factored Loads)

	Lateral Loads
Wave Force Load Factor, γ_W:	1.75
Pile Cap Forces	
Pile Cap Factored Forces (lbs):	16,819.1
Pile Cap Resultant Elevation (ft.):	5.9
Pile Forces	
Single Pile Factored Force (lbs):	54,557.6
Single Pile Resultant Elevation (ft.):	-4.2
Total Pile Reduction Applied (sum for all piles):	4.14
Total Loading on all piles in a single pier (kip):	225.8
Total Force on Main Pier (kips):	242.6
	Lateral
Crest Elevation of Maximum Wave Height (ft):	31.7
Crest Elevation of Significant Wave Height (ft):	27.9

Superstructure

Summary (factored Loads)

Lateral Loads	
Wave Force Load Factor, γ_W:	1.75
Design Case 1	
Quasi-Static Vertical Force (kip/ft):	71.9
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	71.9
Horizontal Force (kip/ft):	3.1
Moment (kip-ft/ft):	3855.3
Design Case 2	
Quasi-Static Vertical Force (kip/ft):	20.8
Slamming Vertical Force (kip/ft):	0.0
Total Vertical Force (kip/ft):	20.8
Horizontal Force (kip/ft):	5.7
Moment (kip-ft/ft):	318.3
Design Case 3a	
Vertical Force (kip/ft):	3.7
Horizontal Force (kip/ft):	1.3
Design Case 3b	
Vertical Force (kip/ft):	1.1
Horizontal Force (kip/ft):	2.3

Inputs

1a. Lateral Wave Input

Datum:	NAVD
Hs (ft):	6.72
Tp (sec):	4.14
Water Surface Elevation	23.2
Bottom Elevation (ft, Datum):	-12.13
Current Speed (ft/s):	7.22

1b. Longitudinal Wave Input

Hs (ft):	0.1
Tp (sec):	3
Current Speed (ft/s):	0.1

2. Structure Input

Critical Structure:	Yes
Span Type:	Girder
Coefficients Selection:	AASHTO Type III
gW (pcf):	64.3
W (ft):	77.2
W* (ft):	72.7
db (ft):	4.8
dg (ft):	2.75
r (ft)	4.5
Pile Cap Height (ft):	5.291666667
Deck Elevation (ft, Datum):	14.04
Pedestal (ft):	0.75
%AIR:	100
Cd, super structure	2.5

Calculation Time Stamp: 5/22/2024 15:54

Lateral

Wsub (ft):	4.5

Longitudinal

Wsub (ft):	77.2
Cd, pile	2
Cm, pile	2.5
A, pile	12.56637061
V, pile	12.56637061
n	6
s	13.5

Program Files Location: C:\Users\msadowski\Downloads\MW Matlab\Bridge Loading\Function_Files

Appendix F. Scour Calculations

50-Year Riverine Scour

Proposed Bridge M-05-001

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 50-yr Riverine	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Channel Contraction Scour	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

1. Calculate critical velocity (V_C) to confirm that the channel has Clear-Water conditions and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Velocity
$K_{u(cv)}$ = 11.17	y = 5.32 ft	D_{50} = 0.00131 ft	$V_{channel}$ = 0.56 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists

If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ = 1.62 ft/s > V_1 = 0.56 ft/sec **Therefore scour type is Clear-Water**

(Critical Velocity for the Beginning of Motion, Clear Water vs. Live Bed, HEC-18, Eq. 6.1, p. 6.2)

Is the bridge in pressure flow?

WSE at Bridge of 2.14 ft < Low Chord Elevation of 9.98 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions: Clear-Water contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate Contraction Scour Depth, y_s.

VARIABLES			
$Q_{channel}$	1281	cfs	Discharge in the contracted section of the channel
D_m	0.00164	ft	Diameter of smallest nontransportable particale $1.25D_{50}$
W	127.896	ft	Bttm width of channel contracted section less pier widths
K_u	0.0077	-	English units
y_o	6.88	ft	Avg existing depth in contracted section pre-scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2}\right)^{3/7} = \mathbf{5.59} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.4, p. 6.12)

$$y_s = y_2 - y_o = 5.59 - 6.9 = \mathbf{-1.29} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.5, p. 6.12)

y_s = ***0.00 feet*** (Channel, Clearwater Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 50-yr Riverine	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: M-05-001
Location: Pier 1
Storm: 50-yr Riverine

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	17.70	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	3.42	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.03	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	0.71	ft./sec.
Critical Velocity US, V_c	1.62	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

K1 is based on the column shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.22 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.22

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? Yes

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 4.59 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

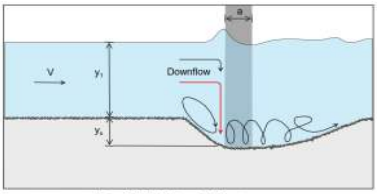


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	0.92
Upstream Froude Number, Fr_1	0.02958

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **4.59 feet** (Local Simple Pier Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

50-Year Riverine Scour

Proposed Bridge W-06-016

Project:	Bridge W-06-016	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 50-yr Riverine Coastal	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Channel Contraction Scour	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

1. Calculate critical velocity (V_C) to confirm that the channel has Clear-Water conditions and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Velocity
$K_{u(cv)}$ = 11.17	y = 7.67 ft	D_{50} = 0.00131 ft	$V_{channel}$ = 0.70 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists

If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ = 1.72 ft/s > V_1 = 0.70 ft/sec **Therefore scour type is Clear-Water**

(Critical Velocity for the Beginning of Motion, Clear Water vs. Live Bed, HEC-18, Eq. 6.1, p. 6.2)

Is the bridge in pressure flow?

WSE at Bridge of 2.14 ft < Low Chord Elevation of 10.17 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions: Clear-Water contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate Contraction Scour Depth, y_s.

VARIABLES			
$Q_{channel}$	2066	cfs	Discharge in the contracted section of the channel
D_m	0.00164	ft	Diameter of smallest nontransportable particale $1.25D_{50}$
W	126.439	ft	Bttm width of channel contracted section less pier widths
K_u	0.0077	-	English units
y_o	10.50	ft	Avg existing depth in contracted section pre-scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2}\right)^{3/7} = \mathbf{8.51} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.4, p. 6.12)

$$y_s = y_2 - y_o = 8.51 - 10.5 = \mathbf{-1.99} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.5, p. 6.12)

y_s = ***0.00 feet*** (Channel, Clearwater Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:** Plymouth	**Page:** 1	**of:** 2	
Subject:	Pro Bridge 50-yr Riverine Coastal	**Computed:** mdbrown	**Date:**	May. 20, 2024	
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown	**Date:**	May. 28, 2024	
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 1
Storm: 50-yr Riverine

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	20.00	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	41.27	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.03	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	0.66	ft./sec.
Critical Velocity US, V_c	1.72	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 2.74 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 2.74

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No
Clear Water Conditions? Yes

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No
Is a/D_{50} > 50? Yes
Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 10.19 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

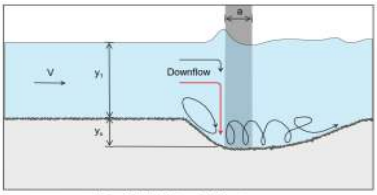


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	2.04
Upstream Froude Number, Fr_1	0.02601

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = 10.19 feet (Local Simple Pier Scour)

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Project:	Bridge W-06-016	**County:** Plymouth	**Page:** 2	**of:** 2	
Subject:	Pro Bridge 50-yr Riverine Coastal	**Computed:** mdbrown	**Date:**	May. 20, 2024	
Task:	Simple Pier Scour - Pier 2	**Checked:** nbrown	**Date:**	May. 28, 2024	
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 2
Storm: 50-yr Riverine

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	23.68	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	5.75	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.02	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	0.53	ft./sec.
Critical Velocity US, V_c	1.72	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.36 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.36

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No
Clear Water Conditions? Yes

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No
Is a/D_{50} > 50? Yes
Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = \quad 4.69 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

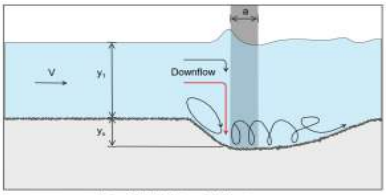

Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	0.94
Upstream Froude Number, Fr_1	0.01916

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **4.69 feet** (Local Simple Pier Scour)

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100-Year Riverine Scour

Proposed Bridge M-05-001

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 100-yr Riverine	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Channel Contraction Scour	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

1. Calculate critical velocity (V_C) to confirm that the channel has Clear-Water conditions and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Velocity
$K_{u(cv)}$ = 11.17	y = 5.24 ft	D_{50} = 0.00131 ft	$V_{channel}$ = 0.64 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists

If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ = 1.61 ft/s > V_1 = 0.64 ft/sec **Therefore scour type is Clear-Water**

(Critical Velocity for the Beginning of Motion, Clear Water vs. Live Bed, HEC-18, Eq. 6.1, p. 6.2)

Is the bridge in pressure flow?

WSE at Bridge of 2.16 ft < Low Chord Elevation of 9.98 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions: Clear-Water contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate Contraction Scour Depth, y_s.

VARIABLES			
$Q_{channel}$	1411	cfs	Discharge in the contracted section of the channel
D_m	0.00164	ft	Diameter of smallest nontransportable particale $1.25D_{50}$
W	130.332	ft	Bttm width of channel contracted section less pier widths
K_u	0.0077	-	English units
y_o	6.69	ft	Avg existing depth in contracted section pre-scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2}\right)^{3/7} = \mathbf{5.98} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.4, p. 6.12)

$$y_s = y_2 - y_o = 5.98 - 6.7 = \mathbf{-0.71} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.5, p. 6.12)

y_s = ***0.00 feet*** (Channel, Clearwater Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 100-yr Riverine	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: M-05-001
Location: Pier 1
Storm: 100-yr Riverine

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	17.44	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	1.50	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.03	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	0.77	ft./sec.
Critical Velocity US, V_c	1.61	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

K1 is based on the column shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.10 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.10

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? Yes

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 4.30 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

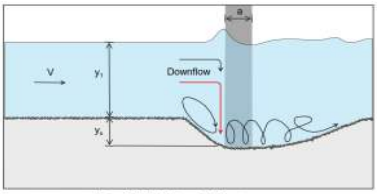

Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	0.86
Upstream Froude Number, Fr_1	0.03265

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **4.30 feet** (Local Simple Pier Scour)

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100-Year Riverine Scour

Proposed Bridge W-06-016

Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 of: 1
Subject:	Pro Bridge 100-yr Riverine Coastal	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	Channel Contraction Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

1. Calculate critical velocity (V_C) to confirm that the channel has Clear-Water conditions and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Velocity
$K_{u(cv)}$ = 11.17	y = 7.71 ft	D_{50} = 0.00131 ft	$V_{channel}$ = 0.78 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists
If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ = 1.72 ft/s > V_1 = 0.78 ft/sec **Therefore scour type is Clear-Water**

(Critical Velocity for the Beginning of Motion, Clear Water vs. Live Bed, HEC-18, Eq. 6.1, p. 6.2)

Is the bridge in pressure flow?

WSE at Bridge of 2.14 ft < Low Chord Elevation of 10.17 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions: Clear-Water contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate Contraction Scour Depth, y_s.

VARIABLES			
$Q_{channel}$	2300	cfs	Discharge in the contracted section of the channel
D_m	0.00164	ft	Diameter of smallest nontransportable particale $1.25D_{50}$
W	126.822	ft	Bttm width of channel contracted section less pier widths
K_u	0.0077	-	English units
y_o	10.49	ft	Avg existing depth in contracted section pre-scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2}\right)^{3/7} = \mathbf{9.30} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.4, p. 6.12)

$$y_s = y_2 - y_o = 9.30 - 10.5 = \mathbf{-1.19} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.5, p. 6.12)

y_s = ***0.00 feet*** (Channel, Clearwater Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:** Plymouth		**Page:** 1	**of:** 2
Subject:	Pro Bridge 100-yr Riverine Coastal	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 1
Storm: 100-yr Riverine

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	20.05	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	41.18	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.03	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	0.74	ft./sec.
Critical Velocity US, V_c	1.72	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 2.74 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 2.74

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No
Clear Water Conditions? Yes

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No
Is a/D_{50} > 50? Yes
Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 10.70 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

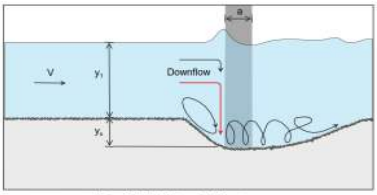


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	2.14
Upstream Froude Number, Fr_1	0.02915

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = ***10.70 feet*** (Local Simple Pier Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:** Plymouth		**Page:** 2	**of:** 2
Subject:	Pro Bridge 100-yr Riverine Coastal	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Simple Pier Scour - Pier 2	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 2
Storm: 100-yr Riverine

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	23.70	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	5.51	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.02	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	0.59	ft./sec.
Critical Velocity US, V_c	1.72	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.34 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.34

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No
Clear Water Conditions? Yes

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No
Is a/D_{50} > 50? Yes
Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = \quad 4.88 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

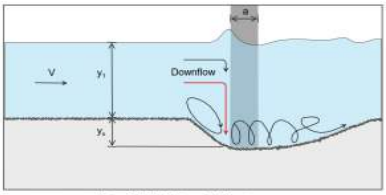


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	0.98
Upstream Froude Number, Fr_1	0.02153

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **4.88 feet** (Local Simple Pier Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

25-Year Coastal Scour

Proposed Bridge M-05-001

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 25-yr Coastal Scour	**Computed:** mdbrown		**Date:** Sep. 19, 2024	
Task:	Channel Contraction Scour	**Checked:** dlh		**Date:** Sep. 19, 2024	
Job #:	10396154	**MassDOT No:** 605311			

1. Calculate critical velocity (V_C) to confirm that the channel has Clear-Water conditions and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Velocity
$K_{u(cv)}$ = 11.17	y = 14.70 ft	D_{50} = 0.00131 ft	$V_{channel}$ = 1.81 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists
If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ = 1.91 ft/s > V_1 = 1.81 ft/sec **Therefore scour type is Clear-Water**

(Critical Velocity for the Beginning of Motion, Clear Water vs. Live Bed, HEC-18, Eq. 6.1, p. 6.2)

Is the bridge in pressure flow?

WSE at Bridge of 6.49 ft < Low Chord Elevation of 9.98 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions: Clear-Water contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate Contraction Scour Depth, y_s.

VARIABLES			
$Q_{channel}$	10278	cfs	Discharge in the contracted section of the channel
D_m	0.00164	ft	Diameter of smallest nontransportable particale $1.25D_{50}$
W	112.596	ft	Bttm width of channel contracted section less pier widths
K_u	0.0077	-	English units
y_o	13.04	ft	Avg existing depth in contracted section pre-scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2}\right)^{3/7} = \mathbf{37.17} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.4, p. 6.12)

$$y_s = y_2 - y_o = 37.17 - 13.0 = \mathbf{24.13} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.5, p. 6.12)

y_s = ***24.13 feet*** (Channel, Clearwater Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 25-yr Coastal Scour	**Computed:** mdbrown		**Date:**	Sep. 19, 2024
Task:	Simple Pier Scour - Pier 1	**Checked:** dlh		**Date:**	Sep. 19, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: M-05-001
Location: Pier 1
Storm: 25-yr coastal

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	25.98	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	14.93	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.13	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	3.76	ft./sec.
Critical Velocity US, V_c	1.91	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.82 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.82

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No
Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No
Is a/D_{50} > 50? Yes
Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 14.82 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

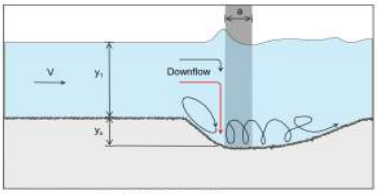


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	2.96
Upstream Froude Number, Fr_1	0.12994

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **14.82 feet** (Local Simple Pier Scour)

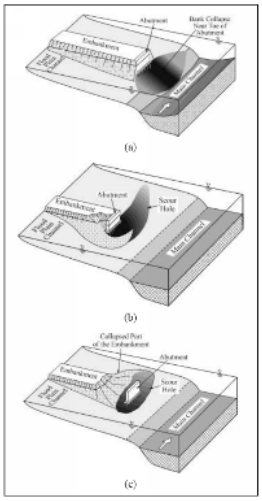
Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	1 of: 2
Subject:	Pro Bridge 25-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	Sep. 19, 2024
Task:	NCHRP Left Abutment Scour	**Checked:**	dlh	**Date:**	Sep. 19, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

Left Abutment

$V_{channel\ US}$ = 1.81 ft/s < V_{crit} = 1.91 ft/s



➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.

For Abutment Scour Condition A Clear-Water Calculations

Left Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	26.60	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	91.28	cfs/ft
Flow Depth Prior to Scour; y_0 =	1.41	ft
q_{2f}/q_f =	3.43	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	40.31	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

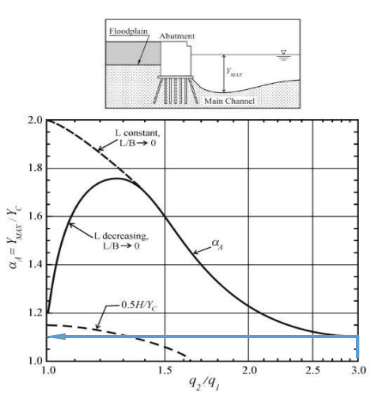


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed floodplain)

α_A =	1.10

$y_{max} = \alpha_B \times y_c$ = HEC-18; eq 8.3	44.34	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	42.93	ft

West Abutment Scour Depth

y_s = 42.93 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	2 **of:** 2
Subject:	Pro Bridge 25-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	Sep. 19, 2024
Task:	NCHRP Right Abutment Scour	**Checked:**	dlh	**Date:**	Sep. 19, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

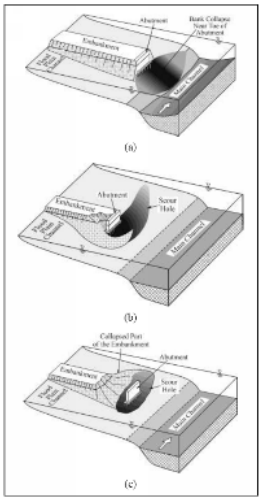
Right Abutment

$V_{channel\ US}$ = 1.81 ft/s < V_{crit} = 1.91 ft/s

➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear-water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Clear-Water Calculations

Right Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	26.60	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	91.28	cfs/ft
Flow Depth Prior to Scour; y_0 =	1.04	ft
q_{2f}/q_f =	3.43	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	40.31	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

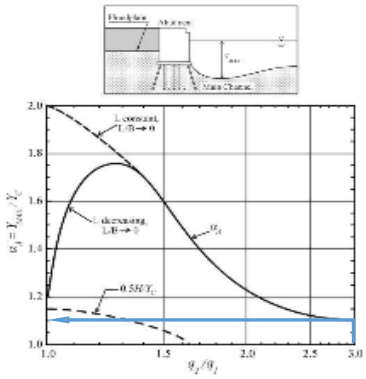


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed bed plane)

α_A =	1.10

$y_{max} = \alpha_B \times y_c$ = HEC-18; eq 8.3	44.34	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	43.30	ft

East Abutment Scour Depth

y_s = 43.30 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

25-Year Coastal Scour

Proposed Bridge W-06-016

Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 **of:** 1
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	Sep. 19, 2024
Task:	Channel Contraction Scour	**Checked:**	dlh	**Date:**	Sep. 19, 2024
Job #:	10396154	**MDOT No:**	605311		

1. Calculate critical velocity (V_C) to confirm that the channel flow is Live-Bed and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Channel Velocity
$K_{u(cv)}$ = 11.17	y_1 = 16.06 ft	D_{50} = 0.00131 ft	V_1 = 2.41 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists

If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ 1.94 ft/s < V_1 = 2.41 ft/sec

Therefore scour type is Live-Bed

Is the bridge in pressure flow?

WSE at Bridge of 6.47 ft < Low Chord Elevation of 10.17 ft

Therefore the bridge is NOT in pressure flow

Verify following conditions Live-Bed contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate K_1 = 0.69

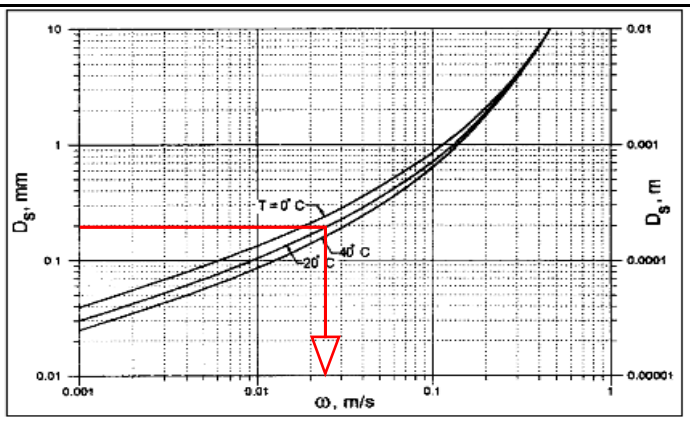
VARIABLES		
D_{50} =	0.40	mm
T =	20	°C,
g =	32.2	ft/s^2
S_1 =	0.00109	ft/ft
y_1 =	16.06	ft

From Fig 6.8		
ω =	0.059	m/s
ω =	0.194	ft/s

$V^* = (g y_1 S_1)^{1/2}$ = 0.75 ft/s

V^*/ω = 3.883 ➔ V^*/ω = > 2 ➔ K_1 = 0.69

V_*/T	k_1	Mode of Bed Material Transport
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge



(Figure 6.8, p.6.11, HEC-18)

3. Calculate Contraction Scour Depth, y_s.

VARIABLES			
y_1 =	16.06	ft	Avg depth in US main channel
Q_1 =	8122	cfs	Flow in US channel transporting sediment
Q_2 =	16332	cfs	Flow in contracted channel
W_1 =	209.57	ft	Bttm width of US channel transporting bed material
W_2 =	135.45	ft	Bttm width of channel contracted section minus piers
y_o =	15.80	ft	Existing depth in channel contracted section pre-scour

$$y_2 = y_1 \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1} = \mathbf{39.48} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.2. p.6.10)

$$y_s = y_2 - y_o = 39.48 - 15.80 = \mathbf{23.68} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.3, p. 6.10)

y_s = **23.68** ***feet*** (Channel Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:** Plymouth		**Page:** 1	**of:** 2
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:** mdbrown		**Date:**	Sep. 19, 2024
Task:	Simple Pier Scour - Pier 1	**Checked:** dlh		**Date:**	Sep. 19, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 1
Storm: 50-yr coastal

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	29.97	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	21.32	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.12	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	3.87	ft./sec.
Critical Velocity US, V_c	1.94	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 2.09 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 2.09

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = \quad 17.60 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

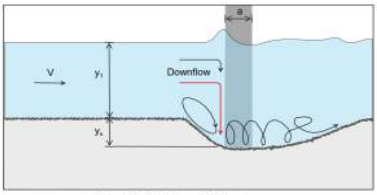


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	3.52
Upstream Froude Number, Fr_1	0.12469

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = 17.60 feet (Local Simple Pier Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:** Plymouth	**Page:** 2	**of:** 2	
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:** mdbrown	**Date:**	Sep. 19, 2024	
Task:	Simple Pier Scour - Pier 2	**Checked:** dlh	**Date:**	Sep. 19, 2024	
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 2
Storm: 50-yr coastal

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft	Upstream Froude Number, Fr_1	0.12	-
Flow Depth at Pier, y_1	32.53	ft.	Equivalent Pier, Le	30.00	ft.
K_u	11.17	English Units	Simple Pier, L	NA	ft.
Pier Width, a	5.00	ft.	Bed Material, D_{50}	0.0013	ft.
No. of Columns at the Bent	6.00	-	Acceleration of Gravity, g	32.20	ft./sec.^{2}
Flow Angle of Attack, θ	15.68	°	Local Approach Velocity, V_1	3.90	ft./sec.
Pier Shape, K_1	1.00	-	Critical Velocity US, V_c	1.94	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.85 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.85

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements		*Wide Pier Requirements*	
D_{50} > 20 mm (0.065 ft)?	No	y_1/a < 0.8?	No
Clear Water Conditions?	No	Is a/D_{50} > 50?	Yes
		Subcritical Flow (Fr <1.0)?	Yes
Coarse Bed?	No (HEC-18 Sec 7.11, p 7.37)	Wide Pier?	No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = \quad 15.80 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

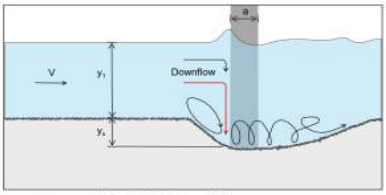


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	3.16
Upstream Froude Number, Fr_1	0.12040

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **15.80 feet** (Local Simple Pier Scour)

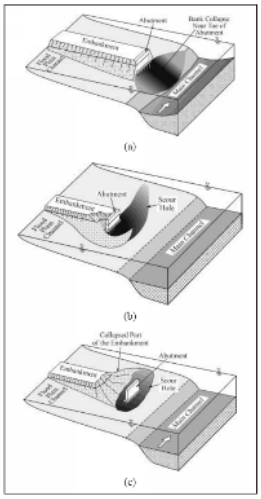
Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 **of:** 2
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	Sep. 19, 2024
Task:	NCHRP Left Abutment Scour	**Checked:**	dlh	**Date:**	Sep. 19, 2024
Job #:	10396154	**MDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

Left Abutment

$V_{Channel\ US}$ = 2.41 ft/s > V_{crit} = 1.94 ft/s



➔ ➔ If the velocities in the Channel US are greater than the critical velocity, suggesting live-bed conditions, then live-bed abutment scour will occur.

The average Channel Velocity is greater than the critical velocity. Therefore, Live-Bed Calculations will be used to estimate abutment scour.

The left abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.

For Abutment Scour Condition A Live-Bed Calculations

Left Abutment Parameters		
Upstream Average Flow Depth; y_1 =	16.06	ft
Upstream Unit Discharge, channel; q_1 =	38.76	cfs/ft
Unit Discharge in Constricted Opening; q_2 =	120.58	cfs/ft
Flow Depth Prior to Scour; y_0 =	0.81	ft
q_2/q_1 =	3.11	
y_c = Flow Depth Inlcuding Contraction Scour y_c = $y_1 (q_{2c}/q_1)^{6/7}$ =	42.47	ft

(HEC-18; eq 8.5)

Applying Scour Condition A Curve for Vertical Wall Abutments

α_A = 1.10

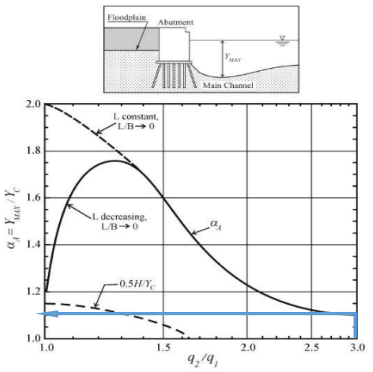


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed floodplain)

$y_{max} = \alpha_A \times y_c$ = HEC-18; eq 8.3	46.72	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	45.91	ft

West Abutment Scour Depth

y_s = 45.91 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 **of:** 2
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	Sep. 19, 2024
Task:	NCHRP Right Abutment Scour	**Checked:**	dlh	**Date:**	Sep. 19, 2024
Job #:	10396154	**MDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

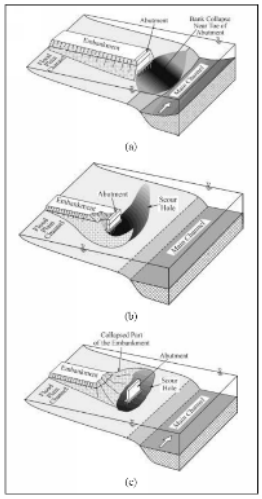
Right Abutment

$V_{channel\ US}$ = 2.41 ft/s > V_{crit} = 1.94 ft/s

➔ ➔ If the velocities in the Channel US are greater than the critical velocity, suggesting live-bed conditions, then live-bed abutment scour will occur.

The average Channel Velocity is greater than the critical velocity. Therefore, Live-Bed Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Live-Bed Calculations

Right Abutment Parameters		
Upstream Average Flow Depth; y_1 =	16.06	ft
Upstream Unit Discharge, channel; q_1 =	38.76	cfs/ft
Unit Discharge in Constricted Opening; q_2 =	120.58	cfs/ft
Flow Depth Prior to Scour; y_0 =	0.84	ft
q_2/q_1 =	3.11	
y_c = Flow Depth Inlcuding Contraction Scour y_c = $y_1 (q_{2c}/q_1)^{6/7}$ =	42.47	ft

(HEC-18; eq 8.5)

Applying Scour Condition A Curve for Vertical Wall Abutments

α_A =	1.10

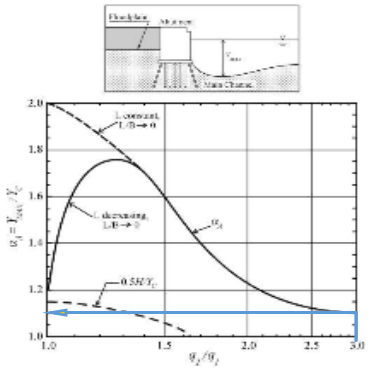


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed footprint)

$y_{max} = \alpha_A \times y_c$ = HEC-18; eq 8.3	46.72	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	45.88	ft

East Abutment Scour Depth

y_s = 45.88 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

50-Year Coastal Scour

Proposed Bridge M-05-001

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:** mdbrown		**Date:** May. 20, 2024	
Task:	Channel Contraction Scour	**Checked:** nbrown		**Date:** May. 28, 2024	
Job #:	10396154	**MassDOT No:** 605311			

1. Calculate critical velocity (V_C) to confirm that the channel has Clear-Water conditions and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Velocity
$K_{u(cv)}$ = 11.17	y = 15.54 ft	D_{50} = 0.00131 ft	$V_{channel}$ = 1.30 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists
If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ = 1.93 ft/s > V_1 = 1.30 ft/sec **Therefore scour type is Clear-Water**

(Critical Velocity for the Beginning of Motion, Clear Water vs. Live Bed, HEC-18, Eq. 6.1, p. 6.2)

Is the bridge in pressure flow?

WSE at Bridge of 8.79 ft < Low Chord Elevation of 9.98 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions: Clear-Water contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate Contraction Scour Depth, y_s.

VARIABLES			
$Q_{channel}$	7561	cfs	Discharge in the contracted section of the channel
D_m	0.00164	ft	Diameter of smallest nontransportable particale $1.25D_{50}$
W	107.292	ft	Bttm width of channel contracted section less pier widths
K_u	0.0077	-	English units
y_o	16.45	ft	Avg existing depth in contracted section pre-scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2}\right)^{3/7} = \mathbf{29.78} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.4, p. 6.12)

$$y_s = y_2 - y_o = 29.78 - 16.5 = \mathbf{13.33} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.5, p. 6.12)

y_s = *13.33 feet* (Channel, Clearwater Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: M-05-001
Location: Pier 1
Storm: 50-yr coastal

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	27.73	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	19.05	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.08	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	2.42	ft./sec.
Critical Velocity US, V_c	1.93	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 2.00 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 2.00

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 13.59 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

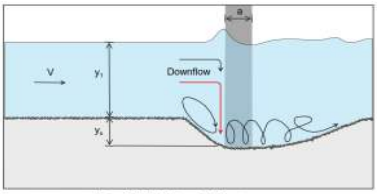


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	2.72
Upstream Froude Number, Fr_1	0.08091

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = 13.59 feet (Local Simple Pier Scour)

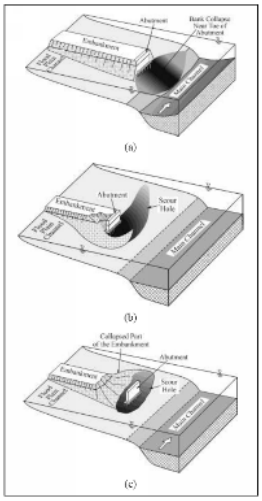
Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	1 of: 2
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Left Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

Left Abutment

$V_{channel\ US}$ = 1.30 ft/s < V_{crit} = 1.93 ft/s



➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.

For Abutment Scour Condition A Clear-Water Calculations

Left Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	20.24	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	70.47	cfs/ft
Flow Depth Prior to Scour; y_0 =	3.78	ft
q_{2f}/q_f =	3.48	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	32.29	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

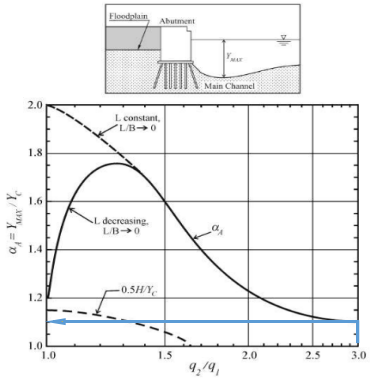


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed floodplain)

α_A =	1.10

$y_{max} = \alpha_B \times y_c$ = HEC-18; eq 8.3	35.52	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	31.75	ft

West Abutment Scour Depth

y_s = 31.75 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	2 **of:** 2
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Right Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

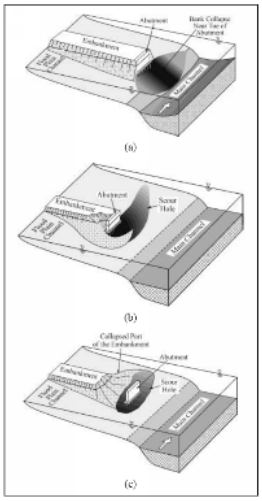
Right Abutment

$V_{channel\ US}$ = 1.30 ft/s < V_{crit} = 1.93 ft/s

➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear-water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Clear-Water Calculations

Right Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	20.24	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	70.47	cfs/ft
Flow Depth Prior to Scour; y_0 =	3.47	ft
q_{2f}/q_f =	3.48	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	32.29	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

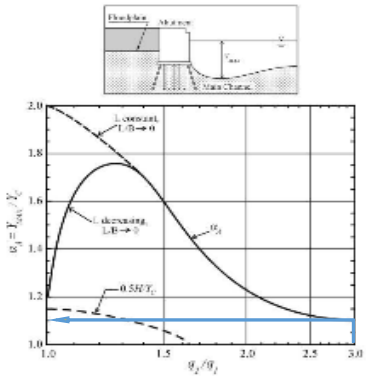


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed bed plane)

α_A =	1.10	
$y_{max} = \alpha_B$ x y_c = HEC-18; eq 8.3	35.52	ft
$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	32.05	ft

East Abutment Scour Depth

y_s = 32.05 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

50-Year Coastal Scour

Proposed Bridge W-06-016

Project:	Bridge W-06-016	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:** mdbrown		**Date:** May. 20, 2024	
Task:	Channel Contraction Scour	**Checked:** nbrown		**Date:** May. 28, 2024	
Job #:	10396154	**MassDOT No:** 605311			

1. Calculate critical velocity (V_C) to confirm that the channel has Clear-Water conditions and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Velocity
$K_{u(cv)}$ = 11.17	y = 17.76 ft	D_{50} = 0.00131 ft	$V_{channel}$ = 1.08 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists
If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3} =$ 1.98 ft/s **>** $V_1 =$ 1.08 ft/sec **Therefore scour type is Clear-Water**

(Critical Velocity for the Beginning of Motion, Clear Water vs. Live Bed, HEC-18, Eq. 6.1, p. 6.2)

Is the bridge in pressure flow?

WSE at Bridge of 8.78 ft **<** Low Chord Elevation of 10.17 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions: Clear-Water contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate Contraction Scour Depth, y_s.

VARIABLES			
$Q_{channel}$	11811	cfs	Discharge in the contracted section of the channel
D_m	0.00164	ft	Diameter of smallest nontransportable particale $1.25D_{50}$
W	120.044	ft	Bttm width of channel contracted section less pier widths
K_u	0.0077	-	English units
y_o	21.11	ft	Avg existing depth in contracted section pre-scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2}\right)^{3/7} = \mathbf{39.64} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.4, p. 6.12)

$$y_s = y_2 - y_o = 39.64 - 21.1 = \mathbf{18.53} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.5, p. 6.12)

$y_s =$ ***18.53 feet*** (Channel, Clearwater Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:** Plymouth	**Page:** 1	**of:** 2	
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:** mdbrown	**Date:**	May. 20, 2024	
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown	**Date:**	May. 28, 2024	
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 1
Storm: 50-yr coastal

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	30.84	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	24.81	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.08	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	2.48	ft./sec.
Critical Velocity US, V_c	1.98	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 2.23 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 2.23

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 15.52 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

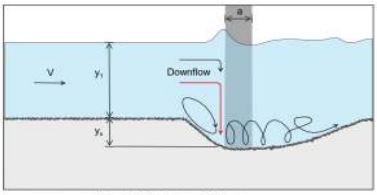


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	3.10
Upstream Froude Number, Fr_1	0.07877

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = 15.52 feet (Local Simple Pier Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:** Plymouth	**Page:** 2	**of:** 2	
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:** mdbrown	**Date:**	May. 20, 2024	
Task:	Simple Pier Scour - Pier 2	**Checked:** nbrown	**Date:**	May. 28, 2024	
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 2
Storm: 50-yr coastal

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	29.55	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	25.45	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.08	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	2.44	ft./sec.
Critical Velocity US, V_c	1.98	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 2.25 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 2.25

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 15.48 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

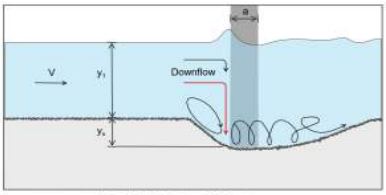


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	3.10
Upstream Froude Number, Fr_1	0.07914

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **15.48 feet** (Local Simple Pier Scour)

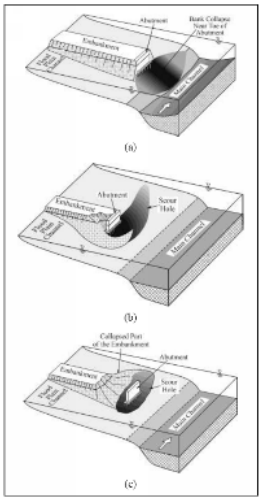
Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 of: 2
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Left Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

Left Abutment

$V_{channel\ US}$ = 1.08 ft/s < V_{crit} = 1.98 ft/s



➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.

For Abutment Scour Condition A Clear-Water Calculations

Left Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	19.11	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	98.39	cfs/ft
Flow Depth Prior to Scour; y_0 =	3.21	ft
q_{2f}/q_f =	5.15	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	42.98	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

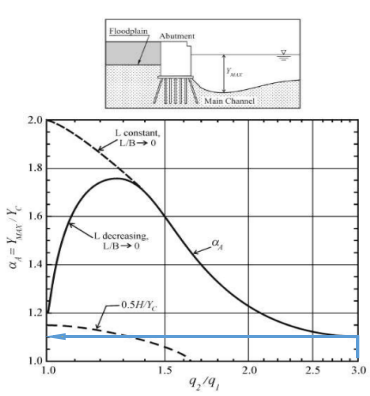


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed floodplain)

α_A =	1.10

$y_{max} = \alpha_B \times y_c$ = HEC-18; eq 8.3	47.28	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	44.07	ft

West Abutment Scour Depth

y_s = 44.07 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	2 **of:** 2
Subject:	Pro Bridge 50-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Right Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

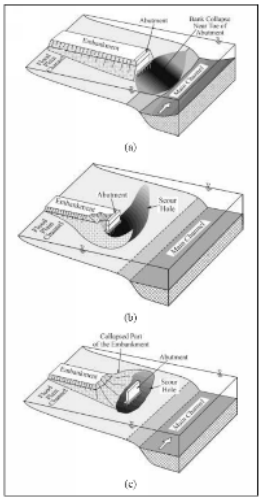
Right Abutment

$V_{channel\ US}$ = 1.08 ft/s < V_{crit} = 1.98 ft/s

➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear-water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Clear-Water Calculations

Right Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	19.11	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	98.39	cfs/ft
Flow Depth Prior to Scour; y_0 =	3.21	ft
q_{2f}/q_f =	5.15	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	42.98	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

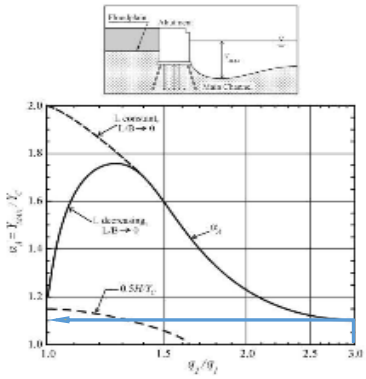


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed bed plane)

α_A =	1.10	
$y_{max} = \alpha_B \times y_c$ = HEC-18; eq 8.3	47.28	ft
$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	44.07	ft

East Abutment Scour Depth

y_s = 44.07 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

100-Year Coastal Scour

Proposed Bridge M-05-001

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 100-yr Coastal Scour	**Computed:** mdbrown		**Date:** May. 20, 2024	
Task:	Channel Contraction Scour	**Checked:** nbrown		**Date:** May. 28, 2024	
Job #:	10396154	**MassDOT No:** 605311			

1. Calculate critical velocity (V_C) to confirm that the channel has Clear-Water conditions and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Velocity
$K_{u(cv)}$ = 11.17	y = 11.52 ft	D_{50} = 0.00131 ft	$V_{channel}$ = 1.69 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists
If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ = 1.84 ft/s > V_1 = 1.69 ft/sec **Therefore scour type is Clear-Water**

(Critical Velocity for the Beginning of Motion, Clear Water vs. Live Bed, HEC-18, Eq. 6.1, p. 6.2)

Is the bridge in pressure flow?

WSE at Bridge of 5.70 ft < Low Chord Elevation of 9.98 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions: Clear-Water contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate Contraction Scour Depth, y_s.

VARIABLES			
$Q_{channel}$	10963	cfs	Discharge in the contracted section of the channel
D_m	0.00164	ft	Diameter of smallest nontransportable particale $1.25D_{50}$
W	131.455	ft	Bttm width of channel contracted section less pier widths
K_u	0.0077	-	English units
y_o	10.36	ft	Avg existing depth in contracted section pre-scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2}\right)^{3/7} = \mathbf{34.41} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.4, p. 6.12)

$$y_s = y_2 - y_o = 34.41 - 10.4 = \mathbf{24.05} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.5, p. 6.12)

y_s = ***24.05 feet*** (Channel, Clearwater Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 100-yr Coastal Scour	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: M-05-001
Location: Pier 1
Storm: 100-yr coastal

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	23.65	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	0.79	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.13	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	3.69	ft./sec.
Critical Velocity US, V_c	1.84	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

K1 is based on the column shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.05 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.05

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = \quad 8.40 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

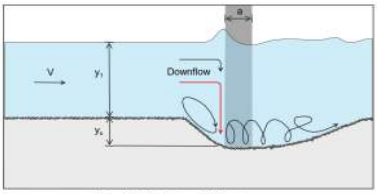


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	1.68
Upstream Froude Number, Fr_1	0.13375

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **8.40 feet** (Local Simple Pier Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	1 **of:** 2
Subject:	Pro Bridge 100-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Right Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

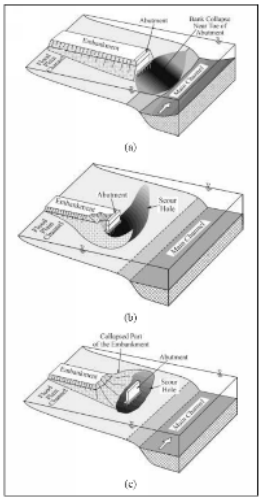
Right Abutment

$V_{channel\ US}$ = 1.69 ft/s < V_{crit} = 1.84 ft/s

➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear-water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Clear-Water Calculations

Right Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	19.42	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	83.40	cfs/ft
Flow Depth Prior to Scour; y_0 =	0.61	ft
q_{2f}/q_f =	4.30	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	37.31	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

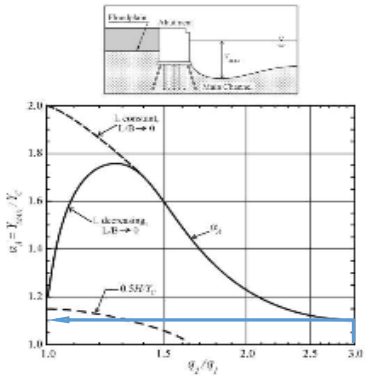


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed bed plane)

α_A =	1.10	
$y_{max} = \alpha_B$ x y_c = HEC-18; eq 8.3	41.04	ft
$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	40.43	ft

West Abutment Scour Depth

y_s = 40.43 feet

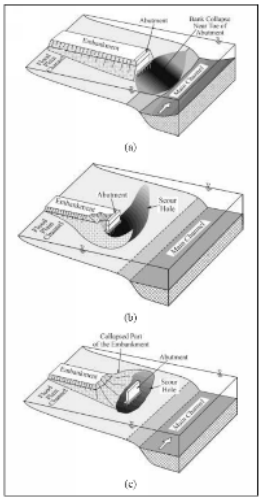
Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	2 of: 2
Subject:	Pro Bridge 100-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Left Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

Left Abutment

$V_{channel\ US}$ = 1.69 ft/s < V_{crit} = 1.84 ft/s



➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.

For Abutment Scour Condition A Clear-Water Calculations

Left Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	19.42	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	83.40	cfs/ft
Flow Depth Prior to Scour; y_0 =	0.35	ft
q_{2f}/q_f =	4.30	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	37.31	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

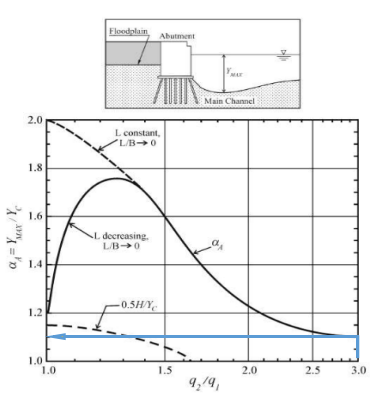


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed floodplain)

α_A =	1.10

$y_{max} = \alpha_B \times y_c$ = HEC-18; eq 8.3	41.04	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	40.69	ft

East Abutment Scour Depth

y_s = 40.69 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

100-Year Coastal Scour

Proposed Bridge W-06-016

Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 **of:** 1
Subject:	Pro Bridge 100-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	Channel Contraction Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MDOT No:**	605311		

1. Calculate critical velocity (V_C) to confirm that the channel flow is Live-Bed and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Channel Velocity
$K_{u(cv)}$ = 11.17	y_1 = 13.78 ft	D_{50} = 0.00131 ft	V_1 = 2.84 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists

If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ 1.89 ft/s < V_1 = 2.84 ft/sec

Therefore scour type is Live-Bed

Is the bridge in pressure flow?

WSE at Bridge of 5.60 ft < Low Chord Elevation of 10.17 ft

Therefore the bridge is NOT in pressure flow

Verify following conditions Live-Bed contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate K_1 = 0.69

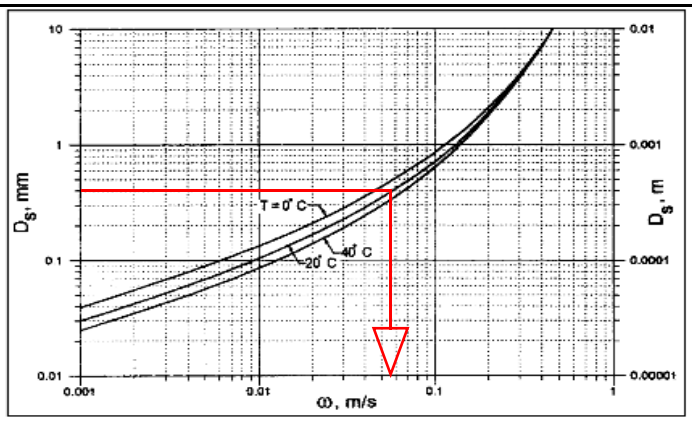
VARIABLES		
D_{50} =	0.40	mm
T =	20	°C,
g =	32.2	ft/s^2
S_1 =	0.00148	ft/ft
y_1 =	13.78	ft

From Fig 6.8		
ω =	0.059	m/s
ω =	0.194	ft/s

$V^* = (g y_1 S_1)^{1/2}$ = 0.81 ft/s

V^*/ω = 4.181 ➔ V^*/ω = > 2 ➔ K_1 = 0.69

V_*/T	k_1	Mode of Bed Material Transport
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge



(Figure 6.8, p.6.11, HEC-18)

3. Calculate Contraction Scour Depth, y_s.

VARIABLES			
y_1 =	13.78	ft	Avg depth in US main channel
Q_1 =	13901	cfs	Flow in US channel transporting sediment
Q_2 =	17294	cfs	Flow in contracted channel
W_1 =	355.10	ft	Bttm width of US channel transporting bed material
W_2 =	151.18	ft	Bttm width of channel contracted section minus piers
y_o =	12.99	ft	Existing depth in channel contracted section pre-scour

$$y_2 = y_1 \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1} = \mathbf{29.96} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.2. p.6.10)

$$y_s = y_2 - y_o = 29.96 - 12.99 = \mathbf{16.97} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.3, p. 6.10)

y_s = **16.97 *feet*** (Channel Contraction Scour)

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Project:	Bridge W-06-016	**County:** Plymouth	**Page:** 1	**of:** 2	
Subject:	Pro Bridge 100-yr Coastal Scour	**Computed:** mdbrown	**Date:**	May. 20, 2024	
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown	**Date:**	May. 28, 2024	
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 1
Storm: 100-yr coastal

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	31.18	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	24.45	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.12	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	3.87	ft./sec.
Critical Velocity US, V_c	1.89	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 2.21 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 2.21

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 18.70 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

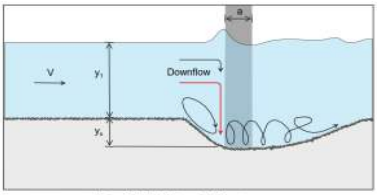

Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	3.74
Upstream Froude Number, Fr_1	0.12207

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **18.70 feet** (Local Simple Pier Scour)

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Project:	Bridge W-06-016	**County:** Plymouth	**Page:** 2	**of:** 2	
Subject:	Pro Bridge 100-yr Coastal Scour	**Computed:** mdbrown	**Date:**	May. 20, 2024	
Task:	Simple Pier Scour - Pier 2	**Checked:** nbrown	**Date:**	May. 28, 2024	
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 2
Storm: 100-yr coastal

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	29.31	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	0.00	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.11	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	3.39	ft./sec.
Critical Velocity US, V_c	1.89	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

K1 is based on the column shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.00 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.00

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = \quad 7.92 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

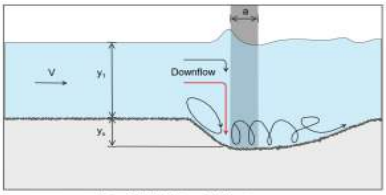

Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	Yes
y_s/a	1.58
Upstream Froude Number, Fr_1	0.11048

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = 7.92 feet (Local Simple Pier Scour)

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Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 of: 2
Subject:	Pro Bridge 100-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Right Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

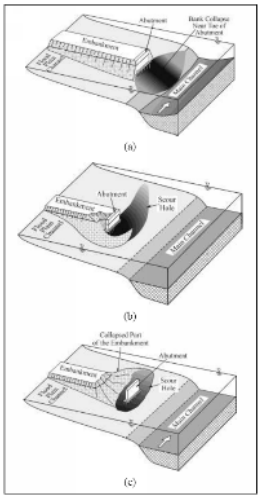
Right Abutment

$V_{channel\ US}$ = 2.84 ft/s > V_{crit} = 1.89 ft/s

➔ ➔ If the velocities in the Channel US are greater than the critical velocity, suggesting live-bed conditions, then live-bed abutment scour will occur.

The average Channel Velocity is greater than the critical velocity. Therefore, Live-Bed Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Live-Bed Calculations

Right Abutment Parameters		
Upstream Average Flow Depth; y_1 =	13.78	ft
Upstream Unit Discharge, channel; q_1 =	39.15	cfs/ft
Unit Discharge in Constricted Opening; q_2 =	114.39	cfs/ft
Flow Depth Prior to Scour; y_0 =	0.21	ft
q_2/q_1 =	2.92	
y_c = Flow Depth Inlcuding Contraction Scour y_c = $y_1(q_{2c}/q_1)^{6/7}$ =	34.55	ft

(HEC-18; eq 8.5)

Applying Scour Condition A Curve for Vertical Wall Abutments

α_A =	1.10

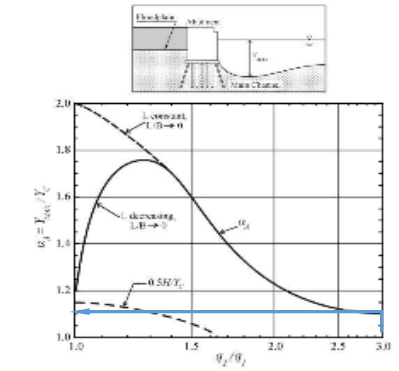


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed footprint)

$y_{max} = \alpha_A \times y_c$ = HEC-18; eq 8.3	38.01	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	37.80	ft

West Abutment Scour Depth

y_s = 37.80 feet

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Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 **of:** 2
Subject:	Pro Bridge 100-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Left Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

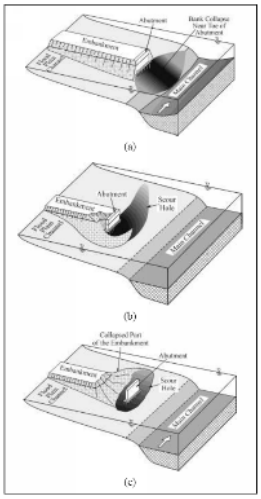
Left Abutment

$V_{Channel\ US}$ = 2.84 ft/s > V_{crit} = 1.89 ft/s

➔ ➔ If the velocities in the Channel US are greater than the critical velocity, suggesting live-bed conditions, then live-bed abutment scour will occur.

The average Channel Velocity is greater than the critical velocity. Therefore, Live-Bed Calculations will be used to estimate abutment scour.

The left abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Live-Bed Calculations

Left Abutment Parameters		
Upstream Average Flow Depth; y_1 =	13.78	ft
Upstream Unit Discharge, channel; q_1 =	39.15	cfs/ft
Unit Discharge in Constricted Opening; q_2 =	114.39	cfs/ft
Flow Depth Prior to Scour; y_0 =	0.38	ft
q_2/q_1 =	2.92	
y_c = Flow Depth Inlcuding Contraction Scour y_c = $y_1 (q_{2c}/q_1)^{6/7}$ =	34.55	ft

(HEC-18; eq 8.5)

Applying Scour Condition A Curve for Vertical Wall Abutments

α_A =	1.10

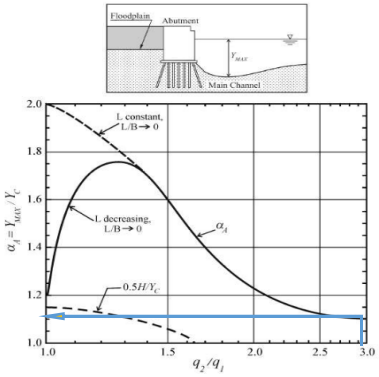


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed floodplain)

$y_{max} = \alpha_A \times y_c$ = HEC-18; eq 8.3	38.01	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	37.63	ft

East Abutment Scour Depth

y_s = 37.63 feet

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50-Year RSLR Coastal Scour

Proposed Bridge M-05-001

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 50-yr RSLR Coastal	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Channel Contraction Scour	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

1. Calculate critical velocity (V_C) to confirm that the channel has Clear-Water conditions and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Velocity
$K_{u(cv)}$ = 11.17	y = 14.29 ft	D_{50} = 0.00131 ft	$V_{channel}$ = 1.19 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists
If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ = 1.91 ft/s > V_1 = 1.19 ft/sec **Therefore scour type is Clear-Water**

(Critical Velocity for the Beginning of Motion, Clear Water vs. Live Bed, HEC-18, Eq. 6.1, p. 6.2)

Is the bridge in pressure flow?

WSE at Bridge of 9.52 ft < Low Chord Elevation of 9.98 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions: Clear-Water contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate Contraction Scour Depth, y_s.

VARIABLES			
$Q_{channel}$	9033	cfs	Discharge in the contracted section of the channel
D_m	0.00164	ft	Diameter of smallest nontransportable particale $1.25D_{50}$
W	129.251	ft	Bttm width of channel contracted section less pier widths
K_u	0.0077	-	English units
y_o	14.35	ft	Avg existing depth in contracted section pre-scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2}\right)^{3/7} = \mathbf{29.57} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.4, p. 6.12)

$$y_s = y_2 - y_o = 29.57 - 14.3 = \mathbf{15.22} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.5, p. 6.12)

y_s = ***15.22 feet*** (Channel, Clearwater Contraction Scour)

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Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 50-yr RSLR Coastal	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: M-05-001
Location: Pier 1
Storm: 50-yr RSLR

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	26.79	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	2.41	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.09	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	2.68	ft./sec.
Critical Velocity US, V_c	1.91	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

K1 is based on the column shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.16 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.16

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 8.18 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

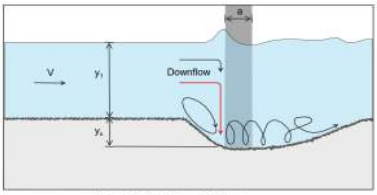


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	1.64
Upstream Froude Number, Fr_1	0.09113

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **8.18 feet** (Local Simple Pier Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	1 **of:** 2
Subject:	Pro Bridge 50-yr RSLR Coastal	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Right Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

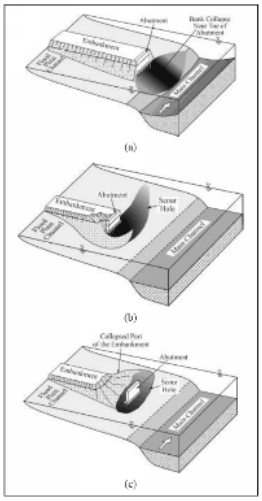
Right Abutment

$V_{channel\ US}$ = 1.19 ft/s < V_{crit} = 1.91 ft/s

➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear-water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Clear-Water Calculations

Right Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	17.08	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	69.89	cfs/ft
Flow Depth Prior to Scour; y_0 =	4.46	ft
q_{2f}/q_f =	4.09	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	32.06	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

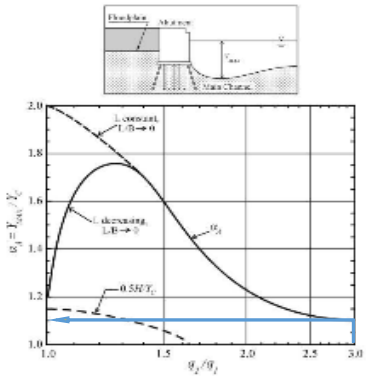


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed bed plane)

α_A =	1.10	
$y_{max} = \alpha_B$ x y_c = HEC-18; eq 8.3	35.27	ft
$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	30.81	ft

West Abutment Scour Depth

y_s = 30.81 feet

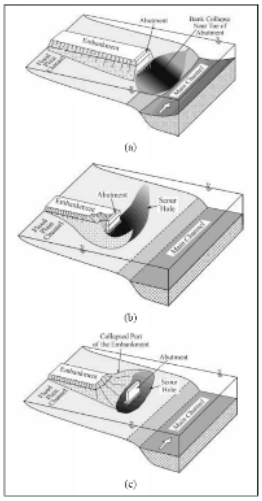
Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	2 of: 2
Subject:	Pro Bridge 50-yr RSLR Coastal	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Left Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

Left Abutment

$V_{channel\ US}$ = 1.19 ft/s < V_{crit} = 1.91 ft/s



➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.

For Abutment Scour Condition A Clear-Water Calculations

Left Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	17.08	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	69.89	cfs/ft
Flow Depth Prior to Scour; y_0 =	4.14	ft
q_{2f}/q_f =	4.09	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	32.06	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

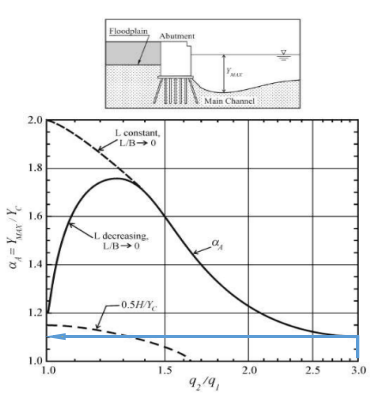


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed floodplain)

α_A =	1.10

$y_{max} = \alpha_B \times y_c$ = HEC-18; eq 8.3	35.27	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	31.12	ft

East Abutment Scour Depth

y_s = 31.12 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

50-Year RSLR Coastal Scour

Proposed Bridge W-06-016

Project:	Bridge W-06-016	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 50-yr RSLR Coastal	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Channel Contraction Scour	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

1. Calculate critical velocity (V_C) to confirm that the channel has Clear-Water conditions and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Velocity
$K_{u(cv)}$ = 11.17	y = 16.96 ft	D_{50} = 0.00131 ft	$V_{channel}$ = 1.85 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists
If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3} =$ 1.96 ft/s **>** $V_1 =$ 1.85 ft/sec **Therefore scour type is Clear-Water**

(Critical Velocity for the Beginning of Motion, Clear Water vs. Live Bed, HEC-18, Eq. 6.1, p. 6.2)

Is the bridge in pressure flow?

WSE at Bridge of 9.39 ft **<** Low Chord Elevation of 10.17 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions: Clear-Water contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate Contraction Scour Depth, y_s.

VARIABLES			
$Q_{channel}$	15312	cfs	Discharge in the contracted section of the channel
D_m	0.00164	ft	Diameter of smallest nontransportable particale $1.25D_{50}$
W	147.156	ft	Bttm width of channel contracted section less pier widths
K_u	0.0077	-	English units
y_o	17.91	ft	Avg existing depth in contracted section pre-scour

$$y_2 = \left(\frac{K_u Q^2}{D_m^{2/3} W^2}\right)^{3/7} = \mathbf{41.59} \text{ ft}$$

(Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.4, p. 6.12)

$$y_s = y_2 - y_o = 41.59 - 17.9 = \mathbf{23.68} \text{ ft}$$

(Average Contraction Scour Depth; HEC-18, Eq. 6.5, p. 6.12)

$y_s =$ ***23.68 feet*** (Channel, Clearwater Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:** Plymouth		**Page:** 1	**of:** 2
Subject:	Pro Bridge 50-yr RSLR Coastal	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 1
Storm: 50-yr RSLR

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	34.20	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	20.94	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.09	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	2.99	ft./sec.
Critical Velocity US, V_c	1.96	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 2.08 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 2.08

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 15.90 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

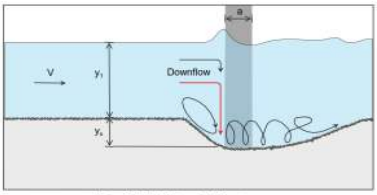


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	3.18
Upstream Froude Number, Fr_1	0.08997

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **15.90 feet** (Local Simple Pier Scour)

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Project:	Bridge W-06-016	**County:** Plymouth	**Page:** 2	**of:** 2	
Subject:	Pro Bridge 50-yr RSLR Coastal	**Computed:** mdbrown	**Date:**	May. 20, 2024	
Task:	Simple Pier Scour - Pier 2	**Checked:** nbrown	**Date:**	May. 28, 2024	
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 2
Storm: 50-yr RSLR

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	32.43	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	6.47	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.09	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	2.83	ft./sec.
Critical Velocity US, V_c	1.96	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.40 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.40

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No
Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No
Is a/D_{50} > 50? Yes
Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 10.36 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

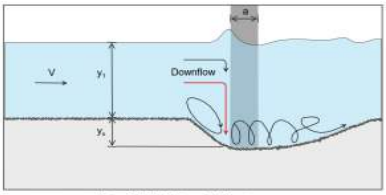

Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	2.07
Upstream Froude Number, Fr_1	0.08747

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = ***10.36 feet*** (Local Simple Pier Scour)

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Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	2 of: 2
Subject:	Pro Bridge 50-yr RSLR Coastal	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Right Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

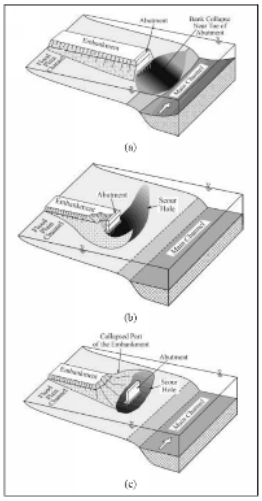
Right Abutment

$V_{channel\ US}$ = 1.85 ft/s < V_{crit} = 1.96 ft/s

➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear-water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Clear-Water Calculations

Right Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	31.41	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	104.05	cfs/ft
Flow Depth Prior to Scour; y_0 =	3.88	ft
q_{2f}/q_f =	3.31	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	45.10	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

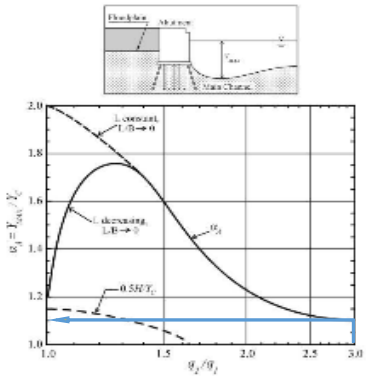


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed bed plane)

α_A =	1.10

$y_{max} = \alpha_B \times y_c$ = HEC-18; eq 8.3	49.61	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	45.73	ft

West Abutment Scour Depth

y_s = 45.73 feet

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Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 of: 2
Subject:	Pro Bridge 50-yr RSLR Coastal	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Left Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

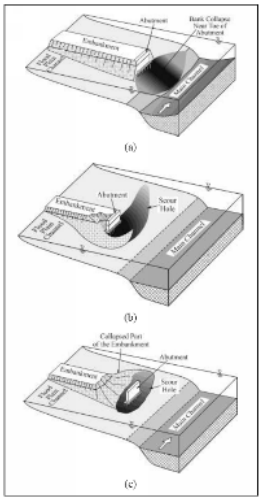
Left Abutment

$V_{channel\ US}$ = 1.85 ft/s < V_{crit} = 1.96 ft/s

➔ ➔ If the velocities in the Channel US are less than the critical velocity, suggesting clear water conditions, then clear-water abutment scour will occur.

The average Channel Velocity is less than the critical velocity.
Therefore, Clear-Water Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Clear-Water Calculations

Left Abutment Parameters		
K_u (english) =	11.17	
D_{50} =	0.0013123	ft
Upstream Channel Unit Discharge; q_1 =	31.41	cfs/ft
Unit Dis. in Constrict. Opening Channel; q_{2f} =	104.05	cfs/ft
Flow Depth Prior to Scour; y_0 =	3.91	ft
q_{2f}/q_f =	3.31	
y_c = Flow Depth Inlcuding Contraction Scour $y_c = (q_{2f}/K_u D_{50}^{1/3})^{6/7}$ =	45.10	ft

(HEC-18; eq 8.6)

Applying Scour Condition A Curve for Vertical Wall Abutments

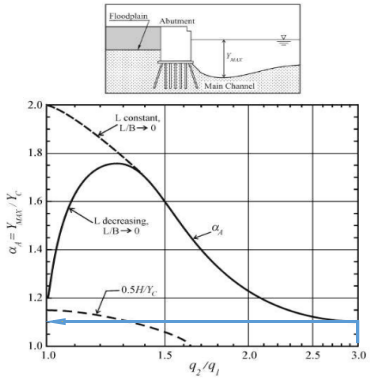


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed floodplain)

α_A =	1.10

$y_{max} = \alpha_B \times y_c$ = HEC-18; eq 8.3	49.61	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	45.70	ft

East Abutment Scour Depth

y_s = 45.70 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

100-Year RSLR Coastal Scour

Proposed Bridge M-05-001

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	1 **of:** 1
Subject:	Pro Bridge 100-yr RSLR Coastal	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	Channel Contraction Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MDOT No:**	605311		

1. Calculate critical velocity (V_C) to confirm that the channel flow is Live-Bed and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Channel Velocity
$K_{u(cv)}$ = 11.17	y_1 = 12.41 ft	D_{50} = 0.00131 ft	V_1 = 2.51 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists

If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ 1.86 ft/s < V_1 = 2.51 ft/sec **Therefore scour type is Live-Bed**

Is the bridge in pressure flow?

WSE at Bridge of 6.18 ft < Low Chord Elevation of 9.98 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions Live-Bed contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate K_1 = 0.69

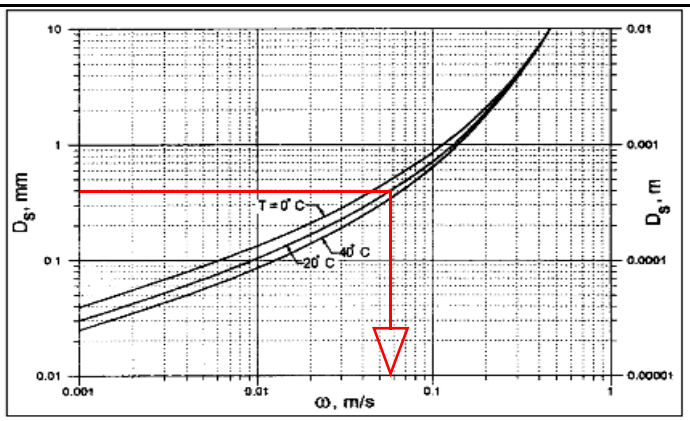
VARIABLES		
D_{50} =	0.40	mm
T =	20	°C,
g =	32.2	ft/s^2
S_1 =	0.00197	ft/ft
y_1 =	12.41	ft

From Fig 6.8		
ω =	0.059	m/s
ω =	0.194	ft/s

$V^* = (g y_1 S_1)^{1/2}$ = 0.89 ft/s

V^*/ω = 4.584 ➔ V^*/ω = > 2 ➔ K_1 = 0.69

V_*/T	k_1	Mode of Bed Material Transport
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge



(Figure 6.8, p.6.11, HEC-18)

3. Calculate Contraction Scour Depth, y_s.

VARIABLES			
y_1 =	12.41	ft	Avg depth in US main channel
Q_1 =	8920	cfs	Flow in US channel transporting sediment
Q_2 =	13675	cfs	Flow in contracted channel
W_1 =	286.88	ft	Bttm width of US channel transporting bed material
W_2 =	125.53	ft	Bttm width of channel contracted section minus piers
y_o =	11.27	ft	Existing depth in channel contracted section pre-scour

$$y_2 = y_1 \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1} = \mathbf{31.66} \text{ ft}$$ (Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.2. p.6.10)

$$y_s = y_2 - y_o = 31.66 - 11.27 = \mathbf{20.40} \text{ ft}$$ (Average Contraction Scour Depth; HEC-18, Eq. 6.3, p. 6.10)

y_s = **20.40** ***feet*** (Channel Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:** Plymouth		**Page:** 1	**of:** 1
Subject:	Pro Bridge 100-yr RSLR Coastal	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: M-05-001
Location: Pier 1
Storm: 100-yr RSLR

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	24.58	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	5.20	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.16	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	4.48	ft./sec.
Critical Velocity US, V_c	1.86	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.32 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.32

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 11.53 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

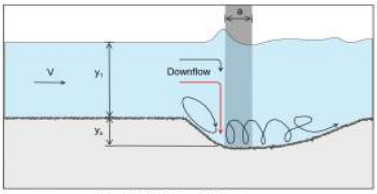


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	2.31
Upstream Froude Number, Fr_1	0.15910

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = 11.53 feet (Local Simple Pier Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	1 **of:** 2
Subject:	Pro Bridge 100-yr RSLR Coastal	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Right Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

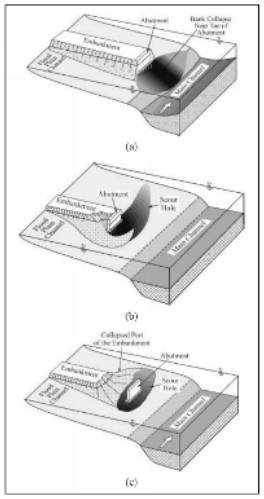
Right Abutment

$V_{channel\ US}$ = 2.51 ft/s > V_{crit} = 1.86 ft/s

➔ ➔ If the velocities in the Channel US are greater than the critical velocity, suggesting live-bed conditions, then live-bed abutment scour will occur.

The average Channel Velocity is greater than the critical velocity. Therefore, Live-Bed Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Live-Bed Calculations

Right Abutment Parameters		
Upstream Average Flow Depth; y_1 =	12.41	ft
Upstream Unit Discharge, channel; q_1 =	31.09	cfs/ft
Unit Discharge in Constricted Opening; q_2 =	108.94	cfs/ft
Flow Depth Prior to Scour; y_0 =	0.76	ft
q_2/q_1 =	3.50	
y_c = Flow Depth Inlcuding Contraction Scour y_c = $y_1(q_{2c}/q_1)^{6/7}$ =	36.36	ft

(HEC-18; eq 8.5)

Applying Scour Condition A Curve for Vertical Wall Abutments

α_A =	1.10

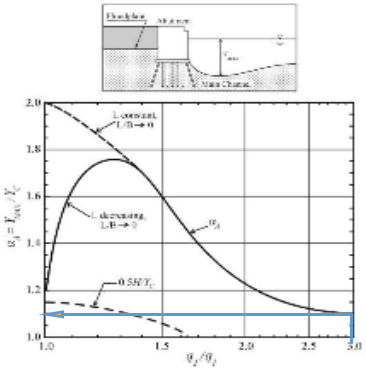


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed footprint)

$y_{max} = \alpha_A \times y_c$ = HEC-18; eq 8.3	39.99	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	39.23	ft

West Abutment Scour Depth

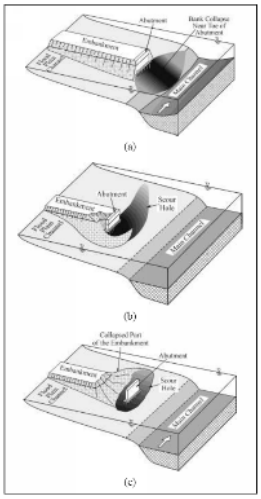
y_s = 39.23 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	2 **of:** 2
Subject:	Pro Bridge 100-yr RSLR Coastal	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Left Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

Left Abutment



$V_{Channel\ US}$ = 2.51 ft/s > V_{crit} = 1.86 ft/s

➔ ➔ If the velocities in the Channel US are greater than the critical velocity, suggesting live-bed conditions, then live-bed abutment scour will occur.

The average Channel Velocity is greater than the critical velocity. Therefore, Live-Bed Calculations will be used to estimate abutment scour.

The left abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.

For Abutment Scour Condition A Live-Bed Calculations

Left Abutment Parameters		
Upstream Average Flow Depth; y_1 =	12.41	ft
Upstream Unit Discharge, channel; q_1 =	31.09	cfs/ft
Unit Discharge in Constricted Opening; q_2 =	108.94	cfs/ft
Flow Depth Prior to Scour; y_0 =	0.81	ft
q_2/q_1 =	3.50	
y_c = Flow Depth Inlcuding Contraction Scour y_c = $y_1 (q_{2c}/q_1)^{6/7}$ =	36.36	ft

(HEC-18; eq 8.5)

Applying Scour Condition A Curve for Vertical Wall Abutments

α_A =	1.10

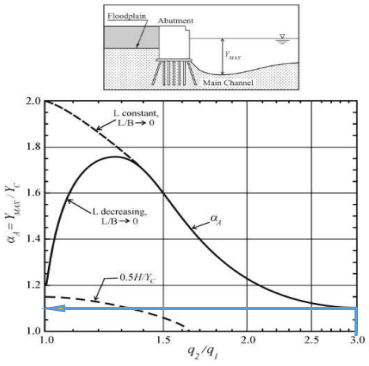


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed floodplain)

$y_{max} = \alpha_A \times y_c$ = HEC-18; eq 8.3	39.99	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	39.18	ft

East Abutment Scour Depth

y_s = 39.18 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

100-Year RSLR Coastal Scour

Proposed Bridge W-06-016

Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 **of:** 1
Subject:	Pro Bridge 100-yr RSLR Coastal	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	Channel Contraction Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MDOT No:**	605311		

1. Calculate critical velocity (V_C) to confirm that the channel flow is Live-Bed and verify that the bridge is NOT in pressure flow.

given for Eng Units	Avg Depth US	D_{50} = 0.40 mm ↓	US Avg Channel Velocity
$K_{u(cv)}$ = 11.17	y_1 = 17.39 ft	D_{50} = 0.00131 ft	V_1 = 2.96 ft/sec

If $V_c > V_1$ then Clear-Water Contraction Scour exists

If $V_c < V_1$ then Live-Bed Contraction Scour exists

$V_C = K_{u(cv)} y_1^{1/6} D_{50}^{1/3}$ 1.97 ft/s < V_1 = 2.96 ft/sec **Therefore scour type is Live-Bed**

Is the bridge in pressure flow?

WSE at Bridge of 8.86 ft < Low Chord Elevation of 10.17 ft **Therefore the bridge is NOT in pressure flow**

Verify following conditions Live-Bed contraction scour occur in the channel AND the bridge is NOT in pressure flow.

Yes, both conditions are met.

2. Calculate K_1 = 0.69

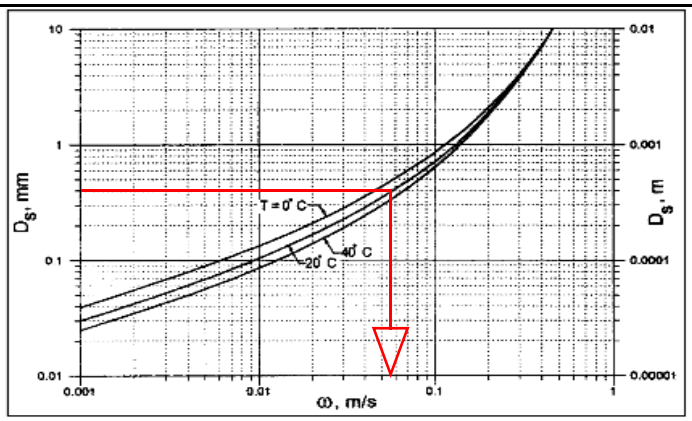
VARIABLES		
D_{50} =	0.40	mm
T =	20	°C,
g =	32.2	ft/s^2
S_1 =	0.00172	ft/ft
y_1 =	17.39	ft

From Fig 6.8		
ω =	0.059	m/s
ω =	0.194	ft/s

$V^* = (g y_1 S_1)^{1/2}$ = 0.98 ft/s

V^*/ω = 5.075 ➔ V^*/ω = > 2 ➔ K_1 = 0.69

V_*/T	k_1	Mode of Bed Material Transport
<0.50	0.59	Mostly contact bed material discharge
0.50 to 2.0	0.64	Some suspended bed material discharge
>2.0	0.69	Mostly suspended bed material discharge



(Figure 6.8, p.6.11, HEC-18)

3. Calculate Contraction Scour Depth, y_s.

VARIABLES			
y_1 =	17.39	ft	Avg depth in US main channel
Q_1 =	18456	cfs	Flow in US channel transporting sediment
Q_2 =	26466	cfs	Flow in contracted channel
W_1 =	358.32	ft	Bttm width of US channel transporting bed material
W_2 =	146.01	ft	Bttm width of channel contracted section minus piers
y_o =	17.24	ft	Existing depth in channel contracted section pre-scour

$$y_2 = y_1 \left(\frac{Q_2}{Q_1}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{k_1} = \mathbf{44.01} \text{ ft}$$ (Post Contraction Scour Equilibrium Flow Depth at Bridge; HEC-18, Eq. 6.2. p.6.10)

$$y_s = y_2 - y_o = 44.01 - 17.24 = \mathbf{26.77} \text{ ft}$$ (Average Contraction Scour Depth; HEC-18, Eq. 6.3, p. 6.10)

y_s = **26.77 *feet*** (Channel Contraction Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:** Plymouth	**Page:** 1	**of:** 2	
Subject:	Pro Bridge 100-yr RSLR Coastal	**Computed:** mdbrown	**Date:**	May. 20, 2024	
Task:	Simple Pier Scour - Pier 1	**Checked:** nbrown	**Date:**	May. 28, 2024	
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 1
Storm: 100-yr RSLR

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	35.08	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	21.09	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.15	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	4.92	ft./sec.
Critical Velocity US, V_c	1.97	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 2.08 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 2.08

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = 19.83 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

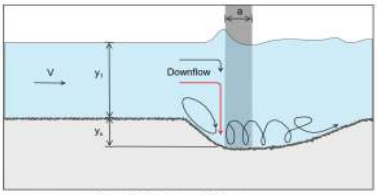


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	3.97
Upstream Froude Number, Fr_1	0.14642

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = **19.83 feet** (Local Simple Pier Scour)

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:** Plymouth		**Page:** 2	**of:** 2
Subject:	Pro Bridge 100-yr RSLR Coastal	**Computed:** mdbrown		**Date:**	May. 20, 2024
Task:	Simple Pier Scour - Pier 2	**Checked:** nbrown		**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:** 605311			

Bridge: W-06-016
Location: Pier 2
Storm: 100-yr RSLR

*These calculations are for bents with a group of multiple simple piers (multiple columns skewed to the flow).

1. Input Hydraulic & Pier Parameters

Spacing bw Columns	8.50	ft
Flow Depth at Pier, y_1	33.17	ft.
K_u	11.17	English Units
Pier Width, a	5.00	ft.
No. of Columns at the Bent	6.00	-
Flow Angle of Attack, θ	7.26	°
Pier Shape, K_1	1.00	-

Upstream Froude Number, Fr_1	0.14	-
Equivalent Pier, Le	30.00	ft.
Simple Pier, L	NA	ft.
Bed Material, D_{50}	0.0013	ft.
Acceleration of Gravity, g	32.20	ft./sec.^{2}
Local Approach Velocity, V_1	4.58	ft./sec.
Critical Velocity US, V_c	1.97	ft/s

2. Determine if the spacing between the columns is less than or greater than 5 times the peir width.

This step determines if the spacing between the columns, S, is great enough, five times the column width, to scour individually or as a group.

$S =$ 8.50 ft < 25 ft ⟶ Therefore, each pier's scour impacts the neighboring piers.
Equivalent pier scour calculations should be used.

(HEC-18, p. 7.23, Figure 7.14 and Section 7.6, p. 7.22)

3. Determine K_1, K_2, and K_3

If attack angle is greater than 5°, K1=1.0 regardless of pier nose shape (HEC-18, p. 7.4, Table 7.1, Note 1, p. 7.5)

$K_1 =$ 1.0

Le/a 6.00 If Le/a is larger than 12, use Le/a = 12 as a maximum in equation 7.4

$K2 = (\cos\theta + (Le/a)\sin\theta)0.65 =$ 1.44 K2 will use the value of Le acting as an equivalent pier. (HEC-18 eq. 7.4, Note 1, p. 7.5)

$K_2 =$ 1.44

K_3 (Bed Condition Correction Factor) = Small Dunes Assumed HEC-18 Tbl 7.3, p 7.5)

$K_3 =$ 1.1

3. Verify condition is NOT Coarse Bed or Wide Pier

Coarse Bed Requirements

D_{50} > 20 mm (0.065 ft)? No

Clear Water Conditions? No

Coarse Bed? No (HEC-18 Sec 7.11, p 7.37)

Wide Pier Requirements

y_1/a < 0.8? No

Is a/D_{50} > 50? Yes

Subcritical Flow (Fr <1.0)? Yes

Wide Pier? No (HEC-18 Sec 7.4, p. 7.10)

5. Estimate Pier Scour Depth

$$y_s = 2.0 y_1 k_1 k_2 k_3 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{0.43} = \quad 13.18 \text{ ft}$$

(HEC-18 eq 7.1, p. 7.3)

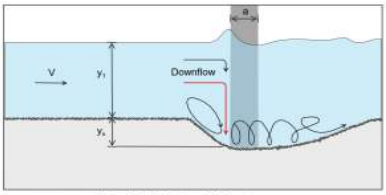


Figure 7.2. Definition sketch for pier scour.

6. Verify Limiting Ratio Values do not apply for Cylindrical or Round Nose Piers

Section 7.1 of HEC-18 recommends the maximum value of y_s/a for cylindrical or round nosed piers aligned with the flow to be taken as 2.4 for Froude Numbers less than or equal to 0.8 and 3.0 for Froude Numbers larger than 0.8.

Piers Cylindrical or Round Nosed	Yes
Piers Aligned with the Flow	No
y_s/a	2.64
Upstream Froude Number, Fr_1	0.14003

Does Limiting Ratio Value Apply	No
Limiting Value Ratio, if applicable	Not Applicable

y_s = ***13.18 feet*** (Local Simple Pier Scour)

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Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 **of:** 2
Subject:	Pro Bridge 100-yr RSLR Coastal	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Right Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

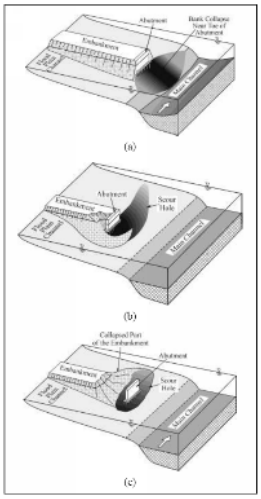
Right Abutment

$V_{channel\ US}$ = 2.96 ft/s > V_{crit} = 1.97 ft/s

➔ ➔ If the velocities in the Channel US are greater than the critical velocity, suggesting live-bed conditions, then live-bed abutment scour will occur.

The average Channel Velocity is greater than the critical velocity. Therefore, Live-Bed Calculations will be used to estimate abutment scour.

The right abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Live-Bed Calculations

Right Abutment Parameters		
Upstream Average Flow Depth; y_1 =	17.39	ft
Upstream Unit Discharge, channel; q_1 =	51.51	cfs/ft
Unit Discharge in Constricted Opening; q_2 =	181.26	cfs/ft
Flow Depth Prior to Scour; y_0 =	3.26	ft
q_2/q_1 =	3.52	
y_c = Flow Depth Inlcuding Contraction Scour y_c = $y_1 (q_{2c}/q_1)^{6/7}$ =	51.14	ft

(HEC-18; eq 8.5)

Applying Scour Condition A Curve for Vertical Wall Abutments

α_A = 1.10

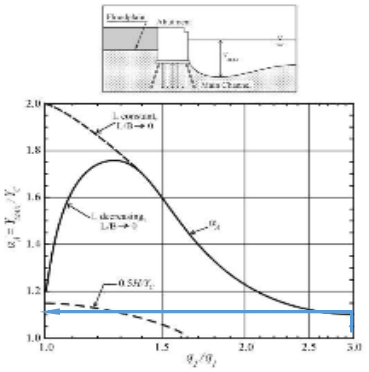


Figure 12-2. Design curve for short-contraction scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (live-bed scour)

$y_{max} = \alpha_A \times y_c$ = HEC-18; eq 8.3	56.25	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	52.99	ft

West Abutment Scour Depth

y_s = 52.99 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 **of:** 2
Subject:	Pro Bridge 100-yr RSLR Coastal	**Computed:**	mdbrown	**Date:**	May. 20, 2024
Task:	NCHRP Left Abutment Scour	**Checked:**	nbrown	**Date:**	May. 28, 2024
Job #:	10396154	**MassDOT No:**	605311		

Determine Condition of Abutment Scour is Live-Bed or Clear-Water and if Scour Condition A, B, or C applies.

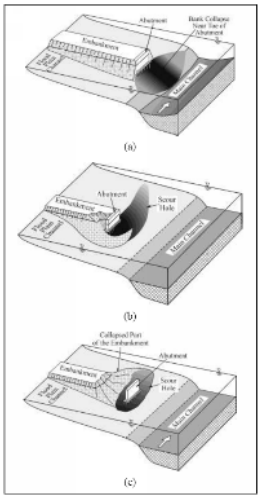
Left Abutment

$V_{Channel\ US}$ = 2.96 ft/s > V_{crit} = 1.97 ft/s

➔ ➔ If the velocities in the Channel US are greater than the critical velocity, suggesting live-bed conditions, then live-bed abutment scour will occur.

The average Channel Velocity is greater than the critical velocity. Therefore, Live-Bed Calculations will be used to estimate abutment scour.

The left abutment is close to the main channel. Abutment scour condition A will be used to estimate abutment scour.



For Abutment Scour Condition A Live-Bed Calculations

Left Abutment Parameters		
Upstream Average Flow Depth; y_1 =	17.39	ft
Upstream Unit Discharge, channel; q_1 =	51.51	cfs/ft
Unit Discharge in Constricted Opening; q_2 =	181.26	cfs/ft
Flow Depth Prior to Scour; y_0 =	3.34	ft
q_2/q_1 =	3.52	
y_c = Flow Depth Inlcuding Contraction Scour y_c = $y_1 (q_{2c}/q_1)^{6/7}$ =	51.14	ft

(HEC-18; eq 8.5)

Applying Scour Condition A Curve for Vertical Wall Abutments

α_A =	1.10

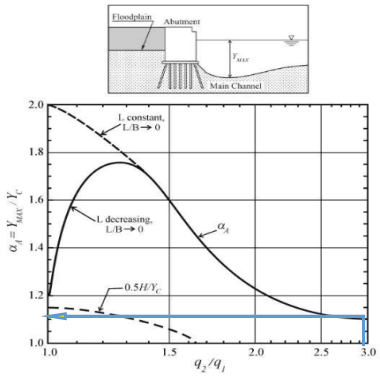


Figure 12-2. Design curve for short-contraction, scour-amplification factor, α_A, for wing-wall abutments subject to Scour Condition A (fixed floodplain)

$y_{max} = \alpha_A \times y_c$ = HEC-18; eq 8.3	56.25	ft

$y_s = y_{max} - y_0$ = HEC-18; eq 8.4	52.91	ft

East Abutment Scour Depth

y_s = 52.91 feet

Hydraulic Engineering Circular No. 18 (HEC-18), "Evaluating Scour at Bridges, Fifth Edition ". April 2012

Appendix G. Scour Countermeasure Calculations

Project:	Bridge M-05-001 = W-06-013	**County:**	Plymouth	**Page:**	1 **of:** 1
Subject:	Pro Bridge 100-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	Sep. 16, 2024
Task:	Abutment Countermeasure	**Checked:**	dlh	**Date:**	Sep. 19, 2024
Job #:	10396154	**MassDOT No:**	605311		

1. Determine K value and design equation based on Froude Number (Fr) obtained from 2D model.

Left Abutment

$Fr_{channel}$ = 0.18 < Fr = 0.80

➔ ➔ If the Froude Number is less than or equal to 0.80, K = 0.89 for spill-through Abutments, K = 1.02 for vertical wall abutments, and use HEC-23 design equation 14.1. If it is greater than 0.80, then K = 0.61 for spill-through abutments, K = 0.69 for vertical wall abutments, and use HEC-23 design equation 14.2.

➔ ➔ Vertical wall abutment for the left abutment

➔ ➔ Since the Froude Number in the LOB is less than or equal to 0.80 and it has a

Vertical wall abutment

K = 1.02 and use Design Equation 14.1

HEC-23 Design Equation 14.1

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

HEC-23 Design Equation 14.2

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

Right Abutment

$Fr_{channel}$ = 0.18 < Fr = 0.80

➔ ➔ If the Froude Number is less than or equal to 0.80, K = 0.89 for spill-through Abutments, K = 1.02 for vertical wall abutments, and use HEC-23 design equation 14.1. If it is greater than 0.80, then K = 0.61 for spill-through abutments, K = 0.69 for vertical wall abutments, and use HEC-23 design equation 14.2.

➔ ➔ Vertical wall abutment for the right abutment

➔ ➔ Since the Froude Number in the ROB is less than or equal to 0.80 and it has a

Vertical wall abutment

K = 1.02 and use Design Equation 14.1

2. Determine the median stone diameter, D_{50}, using the recommended design equation in the form of the Isbash relationship.

Left Abutment		
K =	1.02	
Velocity in Channel (Q/A) =	8.05	ft/sec
*Specific Gravity of Riprap; S_s =	2.65	
Gravitational Acceleration; g =	32.20	ft/sec^2
Max WSE of the Check Flood (ft. NAVD88) =	16.50	ft
MC Thalweg Elevation (MC_{min}) (ft. NAVD88) =	-19.05	ft
Flow Depth at the Thalweg, y_o =	35.55	ft
Using HEC-23 Design Equation 14.1; D_{50} =	1.24	ft
Using HEC-23 Design Equation 14.1; D_{50} =	14.93	in

*Specific gravity of rock riprap assumed minimum - AASHTO T 85

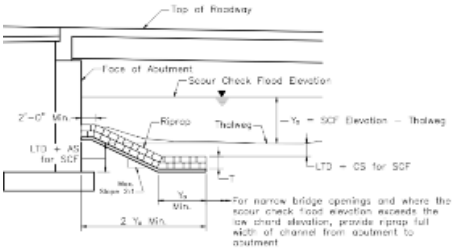
Right Abutment		
K =	1.02	
Velocity in Channel (Q/A) =	8.05	ft/sec
*Specific Gravity of Riprap; S_s =	2.65	
Gravitational Acceleration; g =	32.20	ft/sec^2
Max WSE of the Check Flood (ft. NAVD88) =	16.50	ft
MC Thalweg Elevation (MC_{min}) (ft. NAVD88) =	-19.05	ft
Flow Depth at the Thalweg, y_o =	35.55	ft
Using HEC-23 Design Equation 14.1; D_{50} =	1.24	ft
Using HEC-23 Design Equation 14.1; D_{50} =	14.93	in

*Specific gravity of rock riprap assumed minimum - AASHTO T 85

Table 12.1. Size Gradations for Ten Standard Classes of Riprap.

Nominal Riprap Class by Median Particle Diameter		d_{15}		d_{50}		d_{85}		d_{100}
Class	Size	Min	Max	Min	Max	Min	Max	Max
I	6 in	3.7	5.2	5.7	6.9	7.8	9.2	12.0
II	**9 in**	**5.5**	**7.8**	**8.5**	**10.5**	**11.5**	**14.0**	**18.0**
III	**12 in**	**7.3**	**10.5**	**11.5**	**14.0**	**15.5**	**18.5**	**24.0**
IV	**15 in**	**9.2**	**13.0**	**14.5**	**17.5**	**19.5**	**23.0**	**30.0**
V	18 in	11.0	15.5	17.0	20.5	23.5	27.5	36.0
VI	21 in	13.0	18.5	20.0	24.0	27.5	32.5	42.0
VII	24 in	14.5	21.0	23.0	27.5	31.0	37.0	48.0
VIII	30 in	18.5	26.0	28.5	34.5	39.0	46.0	60.0
IX	36 in	22.0	31.5	34.0	41.5	47.0	55.5	72.0
X	42 in	25.5	36.5	40.0	48.5	54.5	64.5	84.0

Note: Only Classes II, III, and IV are suitable for use in partial grouting applications.



3. Determine riprap extent and layout.

Left Abutment		
Apron extent from toe of abutment =	25.00	ft
(Extent equals twice the flow depth, but less than 25 ft)		
Apron extent u/s and d/s of the embankment =	25.00	ft
(Extent equals twice the flow depth, but not less than 25 ft)		
Thickness of riprap =	2.50	ft
(1.5*D_{50} or D_{100}, whichever is greater)		

Right Abutment		
Apron extent from toe of abutment =	25.00	ft
(Extent equals twice the flow depth, but less than 25 ft)		
Apron extent u/s and d/s of the embankment =	25.00	ft
(Extent equals twice the flow depth, but not less than 25 ft)		
Thickness of riprap =	2.50	ft
(1.5*D_{50} or D_{100}, whichever is greater)		

Hydraulic Engineering Circular No. 23 (HEC-23), "Bridge Scour and Stream Instability Countermeasures, Volume 2". September 2009

Project:	Bridge W-06-016	**County:**	Plymouth	**Page:**	1 **of:** 1
Subject:	Pro Bridge 100-yr Coastal Scour	**Computed:**	mdbrown	**Date:**	Sep. 19, 2024
Task:	Abutment Countermeasure	**Checked:**	dlh	**Date:**	Sep. 19, 2024
Job #:	10396154	**MassDOT No:**	605311		

1. Determine K value and design equation based on Froude Number (Fr) obtained from 2D model.

Left Abutment

$Fr_{channel}$ = 0.27 < Fr = 0.80

➔ ➔ If the Froude Number is less than or equal to 0.80, K = 0.89 for spill-through Abutments, K = 1.02 for vertical wall abutments, and use HEC-23 design equation 14.1. If it is greater than 0.80, then K = 0.61 for spill-through abutments, K = 0.69 for vertical wall abutments, and use HEC-23 design equation 14.2.

➔ ➔ Vertical wall abutment for the left abutment

➔ ➔ Since the Froude Number in the LOB is less than or equal to 0.80 and it has a

Vertical wall abutment

K = 1.02 and use Design Equation 14.1

HEC-23 Design Equation 14.1

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

HEC-23 Design Equation 14.2

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

Right Abutment

$Fr_{channel}$ = 0.27 < Fr = 0.80

➔ ➔ If the Froude Number is less than or equal to 0.80, K = 0.89 for spill-through Abutments, K = 1.02 for vertical wall abutments, and use HEC-23 design equation 14.1. If it is greater than 0.80, then K = 0.61 for spill-through abutments, K = 0.69 for vertical wall abutments, and use HEC-23 design equation 14.2.

➔ ➔ Vertical wall abutment for the right abutment

➔ ➔ Since the Froude Number in the ROB is less than or equal to 0.80 and it has a

Vertical wall abutment

K = 1.02 and use Design Equation 14.1

2. Determine the median stone diameter, D_{50}, using the recommended design equation in the form of the Isbash relationship.

Left Abutment		
K =	1.02	
Velocity in Channel (Q/A) =	8.81	ft/sec
*Specific Gravity of Riprap; S_s =	2.65	
Gravitational Acceleration; g =	32.20	ft/sec^2
Max WSE of the Check Flood (ft. NAVD88) =	16.50	ft
MC Thalweg Elevation (MC_{min}) (ft. NAVD88) =	-24.70	ft
Flow Depth at the Thalweg, y_o =	41.20	ft
Using HEC-23 Design Equation 14.1; D_{50} =	1.49	ft
Using HEC-23 Design Equation 14.1; D_{50} =	17.87	in

*Specific gravity of rock riprap assumed minimum - AASHTO T 85

Right Abutment		
K =	1.02	
Max Velocity in Channel (Q/A) =	8.81	ft/sec
*Specific Gravity of Riprap; S_s =	2.65	
Gravitational Acceleration; g =	32.20	ft/sec^2
Max WSE of the Check Flood (ft. NAVD88) =	16.50	ft
MC Thalweg Elevation (MC_{min}) (ft. NAVD88) =	-24.70	ft
Flow Depth at the Thalweg, y_o =	41.20	ft
Using HEC-23 Design Equation 14.1; D_{50} =	1.49	ft
Using HEC-23 Design Equation 14.1; D_{50} =	17.87	in

*Specific gravity of rock riprap assumed minimum - AASHTO T 85

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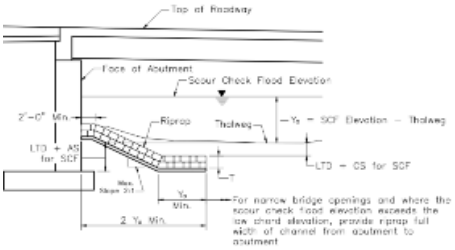
Nominal Riprap Class by Median Particle Diameter		d_{15}		d_{50}		d_{85}		d_{100}
Class	Size	Min	Max	Min	Max	Min	Max	Max
I	6 in	3.7	5.2	5.7	6.9	7.8	9.2	12.0
II	**9 in**	**5.5**	**7.8**	**8.5**	**10.5**	**11.5**	**14.0**	**18.0**
III	**12 in**	**7.3**	**10.5**	**11.5**	**14.0**	**15.5**	**18.5**	**24.0**
IV	**15 in**	**9.2**	**13.0**	**14.5**	**17.5**	**19.5**	**23.0**	**30.0**
V	18 in	11.0	15.5	17.0	20.5	23.5	27.5	36.0
VI	21 in	13.0	18.5	20.0	24.0	27.5	32.5	42.0
VII	24 in	14.5	21.0	23.0	27.5	31.0	37.0	48.0
VIII	30 in	18.5	26.0	28.5	34.5	39.0	46.0	60.0
IX	36 in	22.0	31.5	34.0	41.5	47.0	55.5	72.0
X	42 in	25.5	36.5	40.0	48.5	54.5	64.5	84.0

Note: Only Classes II, III, and IV are suitable for use in partial grouting applications.



3. Determine riprap extent and layout.

Left Abutment		
Apron extent from toe of abutment =	25.00	ft
(Extent equals twice the flow depth, but less than 25 ft)		
Apron extent u/s and d/s of the embankment =	25.00	ft
(Extent equals twice the flow depth, but not less than 25 ft)		
Thickness of riprap =	3.00	ft
(1.5*D_{50} or D_{100}, whichever is greater)		

Right Abutment		
Apron extent from toe of abutment =	25.00	ft
(Extent equals twice the flow depth, but less than 25 ft)		
Apron extent u/s and d/s of the embankment =	25.00	ft
(Extent equals twice the flow depth, but not less than 25 ft)		
Thickness of riprap =	3.00	ft
(1.5*D_{50} or D_{100}, whichever is greater)		

Hydraulic Engineering Circular No. 23 (HEC-23), "Bridge Scour and Stream Instability Countermeasures, Volume 2". September 2009