



# **WSDOT**

# **Scour Workshop**

## **Module 8**

## **Abutment Scour**

**June 1<sup>st</sup>, 2023**

# Scott Hogan

## Senior Hydraulic Engineer FHWA Resource Center



### Current Duties

- Training
- Technical Support
- Technology Development and Deployment



### Background and Experience

- 10 years at FHWA Resource Center
- 7 years at Central Federal Lands Hydraulics Team Lead
- 14 years consulting engineering



### Education

- B.S. Civil Engineering (Colorado State University)
- M.S. Hydraulics (Colorado State University)



### Personal Interests

- Hiking
- Camping
- Fishing and Hunting
- Cycling
- DIY Home Improvement

# Casey Kramer

## Principal River Engineer Natural Waters, LLC



### Current Duties

- Owner of Natural Waters, LLC
- WSDOT HQ staff augmentation team assisting State Hydraulics Engineer



### Background and Experience

- Previous WSDOT State Hydraulic Engineer
- Private sector hydraulics and river engineering consultant
- Research River Engineer



### Education

- B.S. Civil Engineering (Washington State University)
- M.S. River Engineering (University of Iowa – Iowa Institute of Hydraulic Research)



### Personal Interests

- Spending time with family
- Rivers
- Dirt biking, Fishing, Camping, and Coaching/Watching Sports

# Abutment Scour Overview

- Define abutment scour and scour conditions at abutments
- Overview of NCHRP 24-20 abutment scour approach and types of abutment scour
- Summary for how to compute abutment scour
- Steps to compute abutment scour using NCHRP 24-20 approach



*Image Source: Casey Kramer*

# Abutment Scour

- Local scour resulting from the flow obstruction caused by an abutment/embankment
- Contracting flow accelerates and forms vortices



Image Sources: Casey Kramer

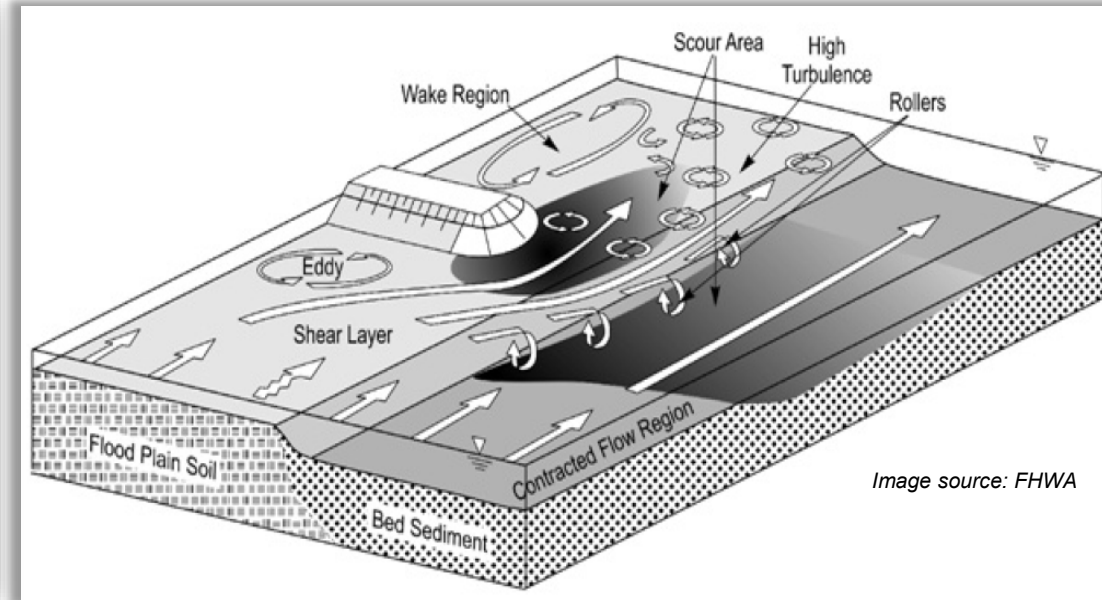


Image source: FHWA

# Abutment Scour

- WSDOT requires using the NCHRP 24-20 approach
- When evaluating the abutment scour condition, consider the channel migration potential over the life of the bridge
- Abutment scour is computed by multiplying contraction scour by an empirically derived amplification factor (includes contraction scour)
- Amplification factors were developed for two abutment configurations and two location scenarios
- See FHWA Scour Workshop and NHI courses for more details



*Image Source: Casey Kramer*



*Image Source: WSDOT*

# Abutment Scour Conditions

## Scour Condition A:

- The abutment is located **near the channel** bank or the channel may migrate into the abutment over the life of the bridge
- Main channel hydraulic parameters are used to compute abutment scour

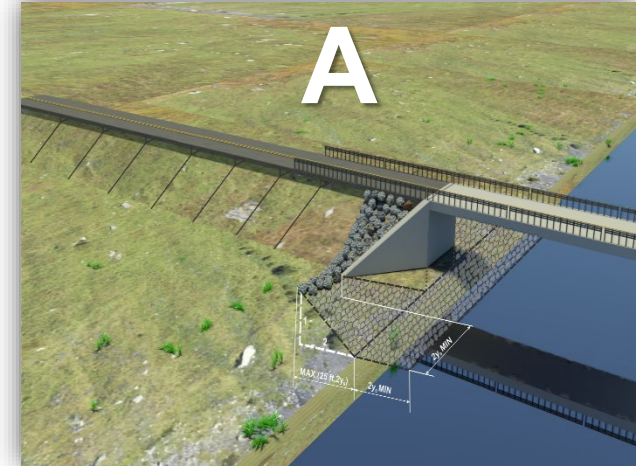


Image source: FHWA

## Scour Condition B:

- The abutment is **set back from the channel** bank far enough that it will not be in contact with the channel over the life of the bridge
- Overbank hydraulic parameters are used to compute abutment scour

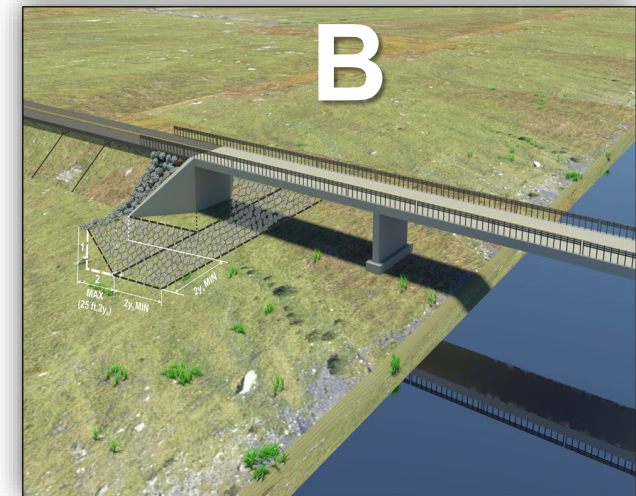


Image source: FHWA

# Abutment Types

- **Spill-through abutments (sloped)**

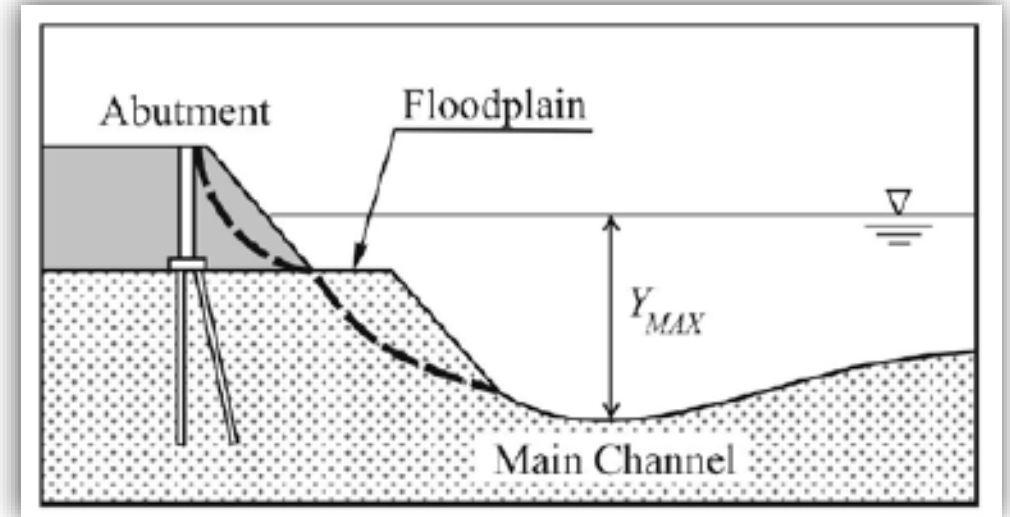


Image source: FHWA

- **Wingwall abutments (vertical)**

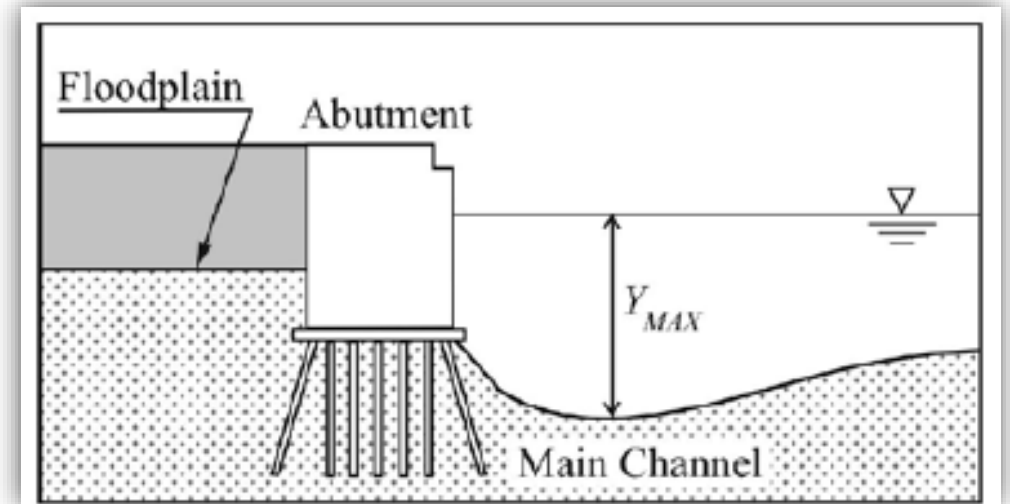


Image source: FHWA



# Abutment Scour

## Four scour amplification curves in HEC-18 (2012)

(Note the clarifications in Figure Captions)

- Scour Condition A, spill-through abutments (Figure 8.9)
  - Scour Condition A, vertical abutments/wingwalls (Figure 8.10)
  - Scour Condition B, spill-through abutments (Figure 8.11)
  - Scour Condition B, vertical abutments/wingwalls (Figure 8.12)
- When  $q_2/q_1$  is low, contraction scour is small and flow separation and turbulence dominate the scour process
  - When  $q_2/q_1$  is large, contraction scour dominates the process and the amplification factor is small

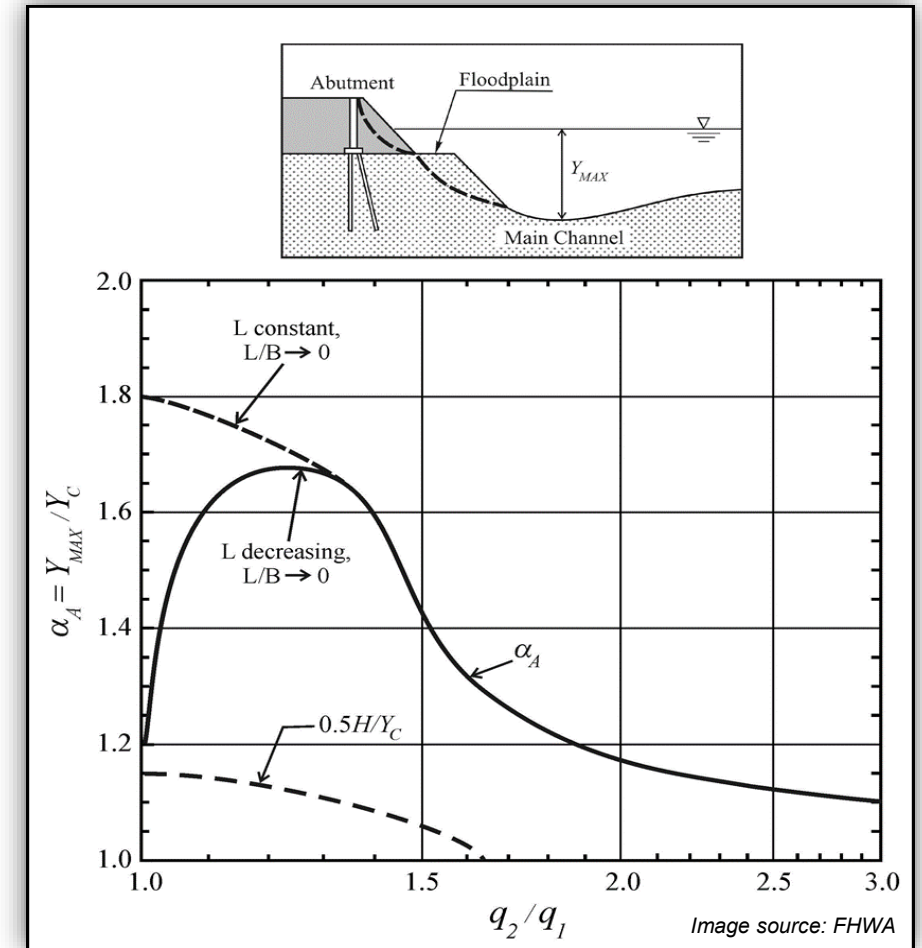


Figure 8.9. Scour amplification factor for spill-through abutments and *live-bed conditions* (Scour Condition A)

# How to Compute Abutment Scour

- Compute contraction scour for all flows up to the scour design flood and scour check flood
- If pressure flow exists (existing bridges), abutment scour cannot be computed using current HEC-18 methods. An abutment scour countermeasure is required

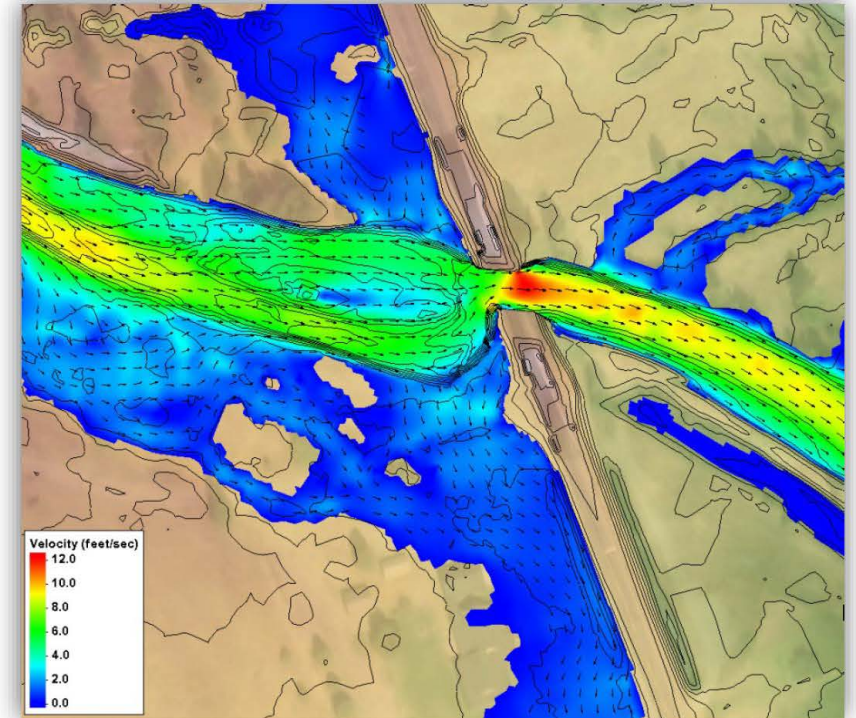


Image Source: Casey Kramer

# How to Compute Abutment Scour

- Determine Scour Condition (A or B)
  - For Scour Condition A, use main channel average hydraulic parameters to compute abutment scour
  - For Scour Condition B, use overbank average hydraulic parameters to compute abutment scour (Most overbank scenarios will be a clear-water condition when vegetation is present)
- Compute unit discharges ( $q_1$  and  $q_2$ ) using hydraulic parameters from contraction scour
- Evaluate the amplification factor ( $\alpha_{A/B}$ ) from HEC-18 Figures 8.9 through 8.12

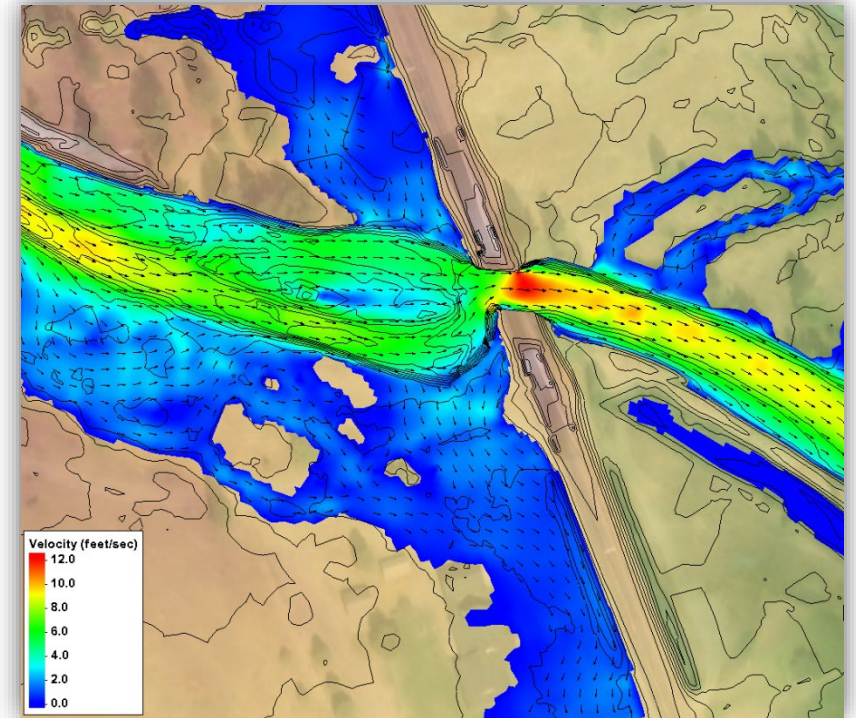
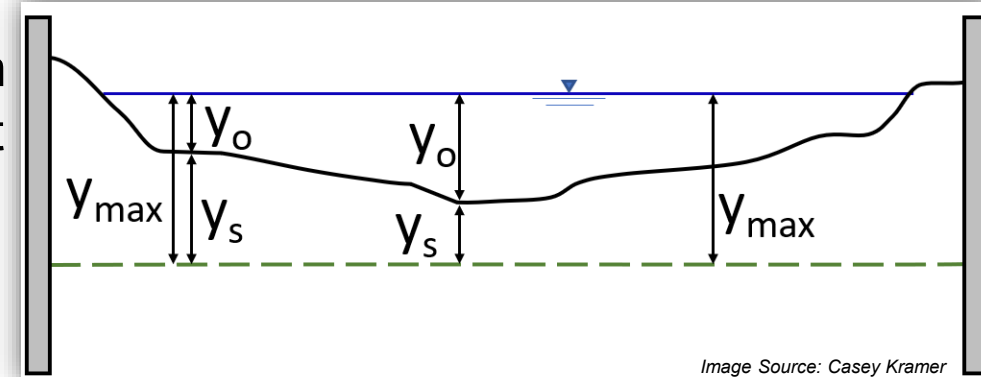


Image Source: Casey Kramer

# How to Compute Abutment Scour

- NCHRP 24-20 estimates a maximum flow depth resulting from abutment scour ( $y_{max}$ )
  - The reference location is used to determine the depth of abutment scour,  $y_s$  (measured below streambed) at that location (e.g.,  $y_s$  is based on the selected location)
  - $y_s$  should always be reported with a reference location (e.g., depth below thalweg for PHD) or the scour elevation at  $y_{max}$  should be documented

*For representation of NCHRP 24-20 terms ONLY*



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

HEC-18 (2012) Eqn. 8.4

# Abutment Scour

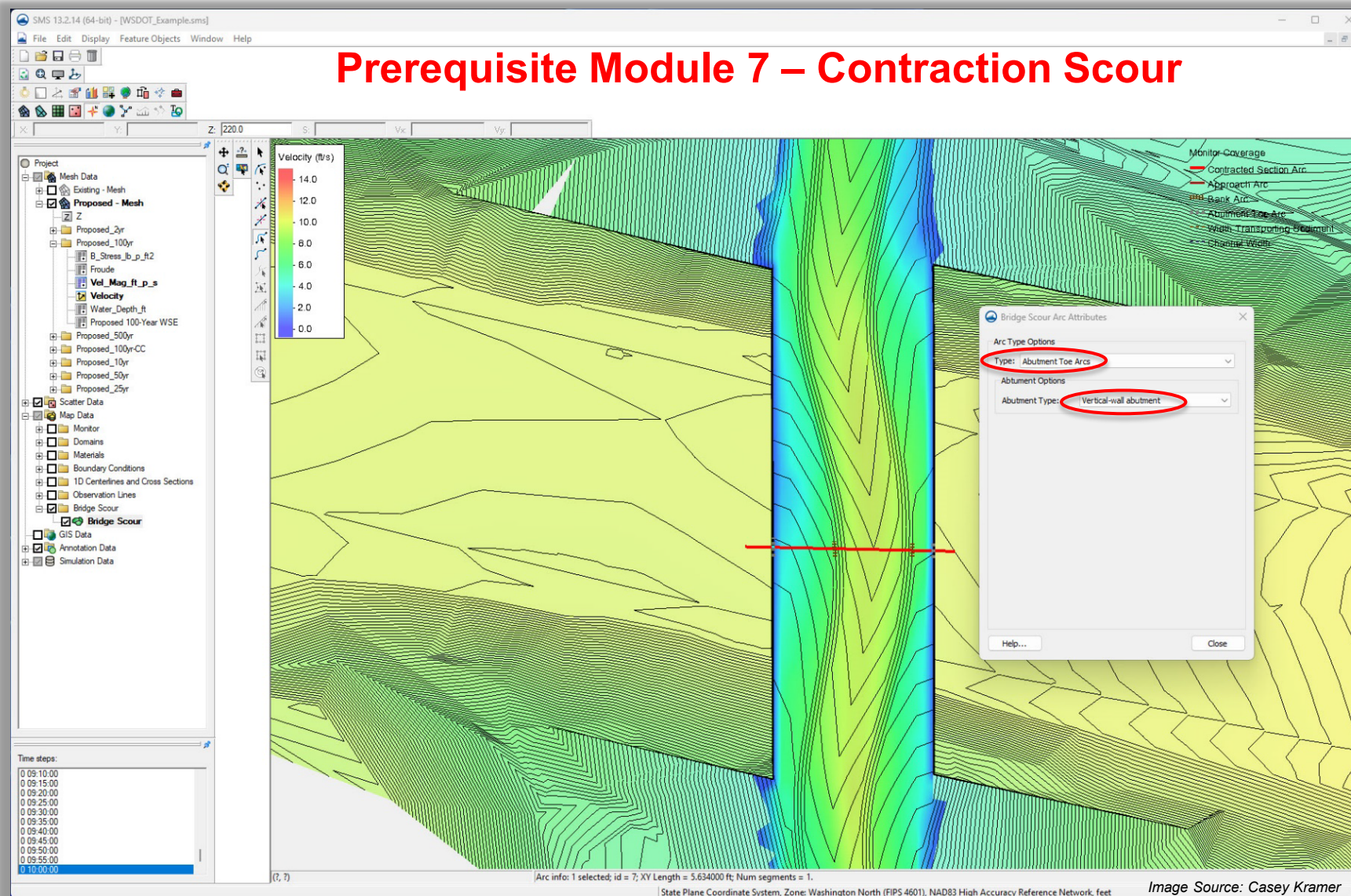
- The following provides an example for computing abutment scour for a PHD
- Key assumptions:
  - The structure type, size and location has not been determined
  - Abutment scour is determined at the selected contracted section location. Per the WSDOT H\_HD template other total scour tables may be necessary to perform scour analysis at appropriate locations
  - Channel profile and geometry is typical through crossing, therefore flow depths are assumed to be uniform. Applying depths of scour at locations other than the location of the selected contraction scour arc needs to be assessed carefully

# Abutment Scour

- The hydraulics engineer of record determines appropriate total scour elevations that are commensurate with the site and acceptable level of risk in coordination with WSDOT
- Ultimate goal is to determine scour elevations at each infrastructure component being designed. Coordination **MUST** happen with the project, geotechnical, and bridge and structures offices to determine appropriate scour elevations to be used for design as the design progresses
- The intent of the next slides is to show an example for how abutment scour should be calculated but does not go into detail of all scenarios and analyses required to develop total scour. Completion of NHI Course 135046 and the FHWA scour workshop is required for more details on computing total scour

# Abutment Scour

## Prerequisite Module 7 – Contraction Scour



# Abutment Scour

The screenshot displays the SMS 13.2.14 (64-bit) interface for a Bridge Scour Analysis. The main window shows a 3D terrain model with a color-coded water depth scale ranging from 0.0 to 8.0 feet. A 'Bridge Scour Analysis' dialog box is open, showing the following configuration:

- Computation Method: NCHRP
- Abutment Scour Parameters:
  - Scour Condition: Clear Water
  - Scour Condition Location: Type a (Main Channel)
  - Abutment Type: Vertical-wall abutment
- Input Parameters:
  - Unit Discharge, Upstream in Main Channel (q1): 26.89 cfs/ft
  - Unit Discharge in Constricted Area (q2): 37.75 cfs/ft
  - D50: 88.900000 mm (Note: 0.2 mm is the lower limit for coh...)
  - Upstream Flow Depth: 3.69 ft
  - Define Shear Stress of Floodplain: [ ]
- Local Scour Parameters:
  - Flow Depth prior to Scour: 0.38 ft (Note: Depth at Abutment Toe)
- Results:
  - q2 / q1: 1.40
  - Average Velocity Upstream: 7.28 ft/s
  - Critical Velocity above which Bed Material of Size D and Sm...: 9.21 ft/s
  - Scour Condition: Clear Water
  - Scour Condition: a (Main Channel)
  - Amplification Factor: 1.71
  - Flow Depth including Contraction Scour: 4.04 ft
  - Scour depth from Long-Term Degradation calculations: 0.00 ft
  - Maximum Flow Depth including Abutment Scour: 6.90 ft (Note: Including the long-term scour de...)
  - Scour Hole Depth: 6.52 ft (Note: Negative values imply 'zero' sco...)
- Scour Hole Parameters:
  - Angle of Repose: 44.00 degrees
  - Ratio of Bottom Width of Scour Hole to Scour Hole Depth: 0.00 (Note: 1.0 means the bottom width will ...)
  - Scour Hole Bottom Width: 0.00 ft
  - Scour Hole Top Width: 6.75 ft

State Plane Coordinate System, Zone: Washington North (FIPS 4601), NAD83 High Accuracy Reference Network, *Image Source: Casey Kramer*



# Abutment Scour

**Bridge Scour Analysis - Input Parameters**

Parameter	Value	Units	Notes
Scour Condition	Clear Water		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	26.89	cfs/ft	
Unit Discharge in Constricted Area (q2)	37.75	cfs/ft	
D50	88.900000	mm	0.2 mm is the lower limit for cohesive m...
Upstream Flow Depth	3.69	ft	
Define Shear Stress of Floodplain			
Flow Depth prior to Scour	0.38	ft	Depth at Abutment Toe

**Bridge Scour Analysis - Results**

Parameter	Value	Units	Notes
q2 / q1	1.40		
Average Velocity Upstream	7.28	ft/s	
Critical Velocity above which Bed Material of Size D and Sm...	9.21	ft/s	
Scour Condition	Clear Water		
Scour Condition	a (Main Channel)		
Amplification Factor	1.71		
Flow Depth including Contraction Scour	4.04	ft	
Scour depth from Long-Term Degradation calculations	0.00	ft	
Maximum Flow Depth including Abutment Scour	6.90	ft	Including the long-term scour depth
Scour Hole Depth	6.52	ft	Negative values imply 'zero' scour depth

**View Values - Main channel (approach):**

Approach section left bank station (ft)	17.709
Approach section right bank station (ft)	52.1215
Approach section main channel width (ft)	34.4125
Approach section main channel flow (cfs)	925.289
Approach section main channel flow area (ft^2)	127.091
Approach section main channel wetted perimeter (ft)	34.6121
Approach section main channel hydraulic radius (ft)	3.67186
Approach section main channel hydraulic depth (ft)	3.69315
(used for average depth upstream of contraction)	
Approach section main channel maximum depth (ft)	4.04756
Approach section main channel unit discharge (cfs/ft)	26.8881
Approach section main channel average velocity (ft/s)	7.28055
Approach section critical velocity (ft/s)	8.74005

**View Values - Contracted SECTION HYDRAULIC PARAMETERS:**

Contracted section left bank station (ft)	26.1455
Contracted section right bank station (ft)	49.0159
Contracted section main channel width (ft)	22.8703
Contracted section main channel adjusted width (ft)	22.8654
(adjusted for pier and skew)	
Contracted section main channel flow (cfs)	863.281
Contracted section main channel flow area (ft^2)	87.3542
Contracted section main channel adjusted flow area (ft^2)	87.3356
(adjusted for piers and skew)	
Contracted section main channel skew angle (degrees)	1.18339
Contracted section main channel wetted perimeter (ft)	22.6641
Contracted section main channel hydraulic radius (ft)	3.8543
Contracted section main channel hydraulic depth (ft)	3.81954
(used for the depth prior to scour in the contracted section)	
Contracted section main channel maximum depth (ft)	4.60198
Contracted section main channel unit discharge (cfs/ft)	37.7548
Contracted section main channel average velocity (ft/s)	9.88254

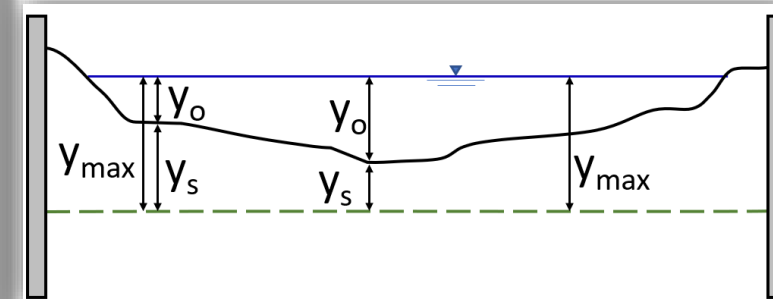


Image Source: Casey Kramer

Image Source: Casey Kramer

# Abutment Scour

**Bridge Scour Analysis - Input Parameters**

Parameter	Value	Units	Notes
Scour Condition	Clear Water		
Scour Condition Location	Type a (Main Channel)		
Abutment Type	Vertical-wall abutment		
Unit Discharge, Upstream in Main Channel (q1)	26.89	cfs/ft	
Unit Discharge in Constricted Area (q2)	37.75	cfs/ft	
D50	88.900000	mm	0.2 mm is the lower limit for coh...
Upstream Flow Depth	3.69	ft	
Define Shear Stress of Floodplain	4.60	ft	Depth at Abutment Toe

**Bridge Scour Analysis - Results**

Parameter	Value	Units	Notes
q2 / q1	1.40		
Average Velocity Upstream	7.28	ft/s	
Critical Velocity above which Bed Material of Size D and Sm...	9.21	ft/s	
Scour Condition	Clear Water		
Scour Condition	a (Main Channel)		
Amplification Factor	1.71		
Flow Depth including Contraction Scour	4.04	ft	
Scour depth from Long-Term Degradation calculations	6.90	ft	Including the long-term scour de...
Maximum Flow Depth including Abutment Scour	6.90	ft	Including the long-term scour de...
Scour Hole Depth	2.30	ft	Negative values imply "zero" sco...

**View Values - Main channel (approach):**

Approach section left bank station (ft)	17.709
Approach section right bank station (ft)	52.1215
Approach section main channel width (ft)	34.4125
Approach section main channel flow (cfs)	925.289
Approach section main channel flow area (ft <sup>2</sup> )	127.091
Approach section main channel wetted perimeter (ft)	34.6121
Approach section main channel hydraulic radius (ft)	3.67186
Approach section main channel hydraulic depth (ft)	3.69315
(used for average depth upstream of contraction)	
Approach section main channel maximum depth (ft)	4.04756
Approach section main channel unit discharge (cfs/ft)	26.8881
Approach section main channel average velocity (ft/s)	7.28055
Approach section critical velocity (ft/s)	8.74005

**View Values - Left overbank (approach):**

Left overbank station (ft):	17.709
Left overbank average flow depth (ft):	1.21274
Left overbank average velocity (ft/s):	5.22495
Left overbank flow width (ft):	12.993
Left overbank flow (cfs):	82.3306
Left overbank unit discharge (cfs/ft):	6.33652

**View Values - Right overbank (approach):**

Right overbank station (ft):	52.1215
Right overbank average flow depth (ft):	2.12396
Right overbank average velocity (ft/s):	2.92759
Right overbank flow width (ft):	13.8618
Right overbank flow (cfs):	86.1936
Right overbank unit discharge (cfs/ft):	6.21808

**CONTRACTED SECTION HYDRAULIC PARAMETERS:**

Entire cross section:	
Energy grade line slope at the contracted section (ft/ft)	0.0348463
Total flow in the contracted section (cfs)	4011.61
Contracted section total flow area (ft <sup>2</sup> )	116.968
Contracted section total wetted perimeter (ft)	56.1825

**View Values - Main channel (contracted section):**

Contracted section left bank station (ft)	26.1455
Contracted section right bank station (ft)	49.0159
Contracted section main channel width (ft)	22.8703
Contracted section main channel adjusted width (ft)	22.8654
(adjusted for skew and skew)	
Contracted section main channel flow (cfs)	863.281
Contracted section main channel flow area (ft <sup>2</sup> )	87.3542
Contracted section main channel adjusted flow area (ft <sup>2</sup> )	87.3356
(adjusted for piers and skew)	
Contracted section main channel skew angle (degrees)	1.18339
Contracted section main channel wetted perimeter (ft)	22.6641
Contracted section main channel hydraulic radius (ft)	3.8543
Contracted section main channel hydraulic depth (ft)	3.81954
(used for the depth prior to scour in the contracted section)	
Contracted section main channel maximum depth (ft)	4.60188
Contracted section main channel unit discharge (cfs/ft)	37.7548
Contracted section main channel average velocity (ft/s)	9.88254

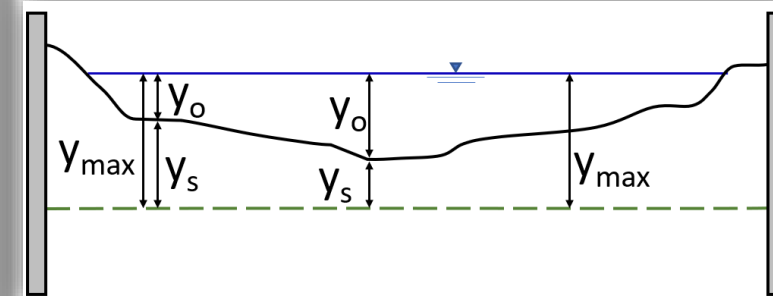


Image Source: Casey Kramer

Image Source: Casey Kramer

# Abutment Scour

To Demonstrate Requirement of All Flows Up To Scour Design Flood and Scour Check Flood **ONLY**

Parameter	Proposed_2yr	Proposed_10yr	Proposed_25yr	Proposed_50yr	Proposed_100yr	Proposed_500yr	Proposed_100yr-CC	Units	Notes
<b>Scenario</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		
<b>Contraction Scour</b>									
Selected Contraction Computation Method	Clear-Water...	Clear-Water ...	Clear-Water ...	Clear-Water ...	Clear-Water a...	Clear-Water an...	Clear-Water and Li...		Clear-Water and Live-Bed Scour
Applied Contraction Scour Depth	0.00	0.00	0.00	0.00	0.00	<b>0.16</b>	0.10	ft	
Clear Water Contraction Scour Depth	<b>-0.37</b>	<b>-0.30</b>	<b>-0.24</b>	<b>-0.17</b>	<b>-0.09</b>	<b>0.16</b>	<b>0.10</b>	ft	Item bolded is the governing contraction scour for scenario
Live Bed Contraction Scour Depth	0.61	0.77	0.73	0.71	0.70	0.71	0.71	ft	Item bolded is the governing contraction scour for scenario
<b>Local Scour at Abutments</b>									
<b>Left Abutment</b>									
Abutment Scour Depth	-0.07	0.67	1.25	1.79	2.30	<b>3.55</b>	3.24	ft	NCHRP Method: Scour Condition A (includes LTD)
Max Flow Depth including Abutment Scour	2.53	4.07	5.05	6.04	6.90	8.85	8.44	ft	Including the long-term scour depth
Total Scour at Abutment	0.00	0.67	1.25	1.79	2.30	<b>3.55</b>	3.24	ft	
<b>Right Abutment</b>									
Abutment Scour Depth	-0.07	0.67	1.25	1.79	2.30	<b>3.55</b>	3.24	ft	NCHRP Method: Scour Condition A (includes LTD)
Max Flow Depth including Abutment Scour	2.53	4.07	5.05	6.04	6.90	8.85	8.44	ft	Including the long-term scour depth
Total Scour at Abutment	0.00	0.67	1.25	1.79	2.30	<b>3.55</b>	3.24	ft	

Depths of Scour are Determined at PHD as Structure Type, Size and Location has not Been Determined

Total Scour Elevation at Each Infrastructure Component is Determined by Interdisciplinary Team as Design Progresses

# Abutment Scour

Clear-water

Parameter	Proposed_2yr	Proposed_10yr	Proposed_25yr	Proposed_50yr	Proposed_100yr	Proposed_500yr	Proposed_100yr-CC	Units	Notes
<b>Scenario</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>		
<b>Contraction Scour</b>									
Selected Contraction Computation Method	Clear-Water...	Clear-Water ...	Clear-Water ...	Clear-Water ...	Clear-Water a...	Clear-Water an...	Clear-Water and Li...		Clear-Water and Live-Bed Scour
Applied Contraction Scour Depth	0.00	0.00	0.00	0.00	0.00	<b>0.16</b>	0.10	ft	
Clear Water Contraction Scour Depth	<b>-0.37</b>	<b>-0.30</b>	<b>-0.24</b>	<b>-0.17</b>	<b>-0.09</b>	<b>0.16</b>	<b>0.10</b>	ft	Item bolded is the governing contraction scour for scenario
Live Bed Contraction Scour Depth	0.61	0.77	0.73	0.71	0.70	0.71	0.71	ft	Item bolded is the governing contraction scour for scenario
<b>Local Scour at Abutments</b>									
<b>Left Abutment</b>									
Abutment Scour Depth	-0.07	0.67	1.25	1.79	2.30	<b>3.55</b>	3.24	ft	NCHRP Method: Scour Condition A (includes LTD)
Max Flow Depth including Abutment Scour	2.53	4.07	5.05	6.04	6.90	8.85	8.44	ft	Including the long-term scour depth
Total Scour at Abutment	0.00	0.67	1.25	1.79	2.30	<b>3.55</b>	3.24	ft	
<b>Right Abutment</b>									
Abutment Scour Depth	-0.07	0.67	1.25	1.79	2.30	<b>3.55</b>	3.24	ft	NCHRP Method: Scour Condition A (includes LTD)
Max Flow Depth including Abutment Scour	2.53	4.07	5.05	6.04	6.90	8.85	8.44	ft	Including the long-term scour depth
Total Scour at Abutment	0.00	0.67	1.25	1.79	2.30	<b>3.55</b>	3.24	ft	

Live-bed

Parameter	Proposed_...	Proposed_10yr	Proposed_25yr	Proposed_50yr	Proposed_100yr	Proposed_500yr	Proposed_100yr-CC	Units	Notes
<b>Scenario</b>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>		
<b>Contraction Scour</b>									
Selected Contraction Computation Method	Clear-Wate...	Clear-Water ...	Clear-Water ...	Clear-Water ...	Clear-Water a...	Clear-Water a...	Clear-Water and ...		Clear-Water and Live-Bed Scour
Applied Contraction Scour Depth	0.00	0.00	0.00	0.00	0.00	<b>0.16</b>	0.10	ft	
Clear Water Contraction Scour Depth	<b>-0.37</b>	<b>-0.30</b>	<b>-0.24</b>	<b>-0.17</b>	<b>-0.09</b>	<b>0.16</b>	<b>0.10</b>	ft	Item bolded is the governing contraction scour for scenario
Live Bed Contraction Scour Depth	0.61	0.77	0.73	0.71	0.70	0.71	0.71	ft	Item bolded is the governing contraction scour for scenario
<b>Local Scour at Abutments</b>									
<b>Left Abutment</b>									
Abutment Scour Depth	1.11	2.53	3.06	3.47	3.84	<b>4.66</b>	4.45	ft	NCHRP Method: Scour Condition A (includes LTD)
Max Flow Depth including Abutment Scour	3.71	5.93	6.86	7.72	8.44	9.96	9.65	ft	Including the long-term scour depth
Total Scour at Abutment	1.11	2.53	3.06	3.47	3.84	<b>4.66</b>	4.45	ft	
<b>Right Abutment</b>									
Abutment Scour Depth	1.11	2.53	3.06	3.47	3.84	<b>4.66</b>	4.45	ft	NCHRP Method: Scour Condition A (includes LTD)
Max Flow Depth including Abutment Scour	3.71	5.93	6.86	7.72	8.44	9.96	9.65	ft	Including the long-term scour depth
Total Scour at Abutment	1.11	2.53	3.06	3.47	3.84	<b>4.66</b>	4.45	ft	