PLAN OF ACTION FOR SCOUR CRITICAL BRIDGES

Drainage Report for

Structure E-15-AH
SH 170 OVER SOUTH BOULDER CREEK

Prepared for:

Colorado Department of Transportation

Prepared by:

Hydrau-Tech, Inc.

May 2013

DOT DEPARTMENT OF TRANSPORTATION

RESPEC CONSULTING & SERVICES

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Hydrau-Tech, Inc. Engineering & Software

ACKNOWLEDGEMENTS

In 1991 the FHWA required all states to provide Plans of Action (POAs) for scour critical bridges. In November 1998 the FHWA reported that CDOT had completed the implementation of POA for its Scour Critical Bridges. Due to a recent, nationwide mandated requirement by FHWA, CDOT was tasked to re-evaluate and update the POAs for each of the 243 bridges identified by CDOT as scour critical or structures with unknown foundations. To complete this task, CDOT created a program to address the scour critical bridges and appointed a consultant team led by RESPEC (previously Moser & Associates Engineering) in partnership with HYDRAU-TECH, Inc. to develop the POAs. The overall goals of the program were:

- For each scour critical bridge, complete a POA.
- For bridges with unknown foundations, identify the depth and type of substructure and determine the potential scour.

For the POA implementation, FHWA requires a multi-disciplinary team with expertise in hydraulics, structural, and geotechnical engineering. In addition to FHWA multi-disciplinary team, CDOT has recognized the importance of other fields such as maintenance, environmental, and construction and has added members with expertise in these fields. Members with maintenance expertise were to address historical flood and maintenance concerns; members with environmental expertise were to address cases where scour countermeasures could have adverse impacts on river habitat; and finally, members with construction and design expertise was added to aid in the detail and setup of construction projects for POA and scour countermeasure implementation.

This POA report was prepared by Hydrau-Tech, Inc. under the direction of Dr. Albert Molinas, President, Hydrau-Tech, Inc. The project engineers who participated in the study and in the preparation of the Hydrau-Tech, Inc.'s POA reports were Mr. William Bailey, Dr. Christopher Thornton, Dr. Chester Watson, Mr. Dustin London, and Mr. Brett Sollenberger. Mr. Adam Pierce, Watershed Scientist, managed the hydraulic surveying and data collection efforts, and was in charge of coordinating between various elements of the study. Mr. Adam Pierce, Mr. Brett Sollenberger, Mr. Tyler Liebman, Mr. Dustin London, and Mr. Jawid Ebadi participated in data collection, sediment analysis, and drafting. Ms. Maggie Molinas edited the Hydrau-Tech, Inc. reports. The structural analysis for the study was conducted by Mr. Dan Bechtold, Vice-President, LONCO Inc. The geotechnical analysis of foundation materials was conducted by Mr. Paul Macklin, YEH and Associates, Inc. Mr. David Delagarza and Mr. Josh Morin, Moser & Associates Engineering provided assistance in the fields for cost analysis, identifying data sources, and structural detailing of countermeasures. Hydrau-Tech, Inc. would like to acknowledge the support and valuable contributions of many individuals involved in the preparation of this report and during the various phases of the POA study including the members of the CDOT Headquarters/FHWA Multi-Disciplinary POA Team and the members of the Field Inspection and the POA Review Team. Hydrau-Tech, Inc. would also like to acknowledge Mr. Rick Moser, RESPEC for his skillful leadership as the Project Manager for the Consultant Team. Special thanks go to Mr. Amanullah Mommandi, CDOT Project Manager, who was the Technical Reviewer of the project. His vast knowledge in hydraulics and scour countermeasures greatly benefited the study. He participated in all site inspection visits, made valuable countermeasure suggestions, organized the POA review meetings, and coordinated the CDOT Headquarters/FHWA Multidisciplinary POA Team meetings, the field inspections, and regional POA Draft report reviews.

The individuals who participated in the POA study and contributed to this report were:

CDOT Project Manager:

Amanullah Mommandi, CDOT Hydraulic Program Manager

CDOT Headquarters/FHWA Multi-Disciplinary POA Team Members:

Amanullah Mommandi, Chair, CDOT Hydraulic Program Manager
Mark Leonard, CDOT Staff Bridge
Timothy Ashenberger, CDOT Project Development
Mark Nord, CDOT Staff Bridge, Management Systems
Jeff Anderson, CDOT Staff Bridge, Inspections
Dave Weider, CDOT Maintenance
C. K. Su, CDOT Geotechnical, Soils and Rockfall
Tom Boyce, CDOT Environmental
Matt Greer, FHWA Structural/Materials Engineer

Field Inspection and POA Review Team Members:

Region 1:

Trever Wang – Staff Bridge, Region 1 & 5
Steve Yip – Staff Bridge, Region 1
Alfred Gross – Region 1, Hydraulics Engineer
Mike DeLong – Region 1, Region Maintenance Superintendent
Larry Dungan – Region 1, Transportation and Maintenance Supervisor
Steve Alderman – Region 1, Staff Bridge, Bridge Coordinator
John Gregory – Region 1, Staff Bridge
Curtis Johnson – Region 1, Maintenance

Region 3:

Behrooz Far – Region 3, Staff Bridge
Stuart Gardner – Region 3, Hydraulics Engineer
Peter Mertes – Region 3, Region Program Engineer
Jason Smith – Region 3, Region Program Engineer
John David – Region 3, Deputy Maintenance Superintendent
Todd J. Blake– Region 3, Traffic, Transportation Maintenance
Hans Egghart – Region 3, Professional Engineer I
Scott Marsh – Region 3, Maintenance
Stephen Bokros – Region 3, Engineer

Region 4:

Richard Osmun – Region 4, Staff Bridge
Tom Moss – Region 4, Staff Bridge
Hoang Bui – Region 4, Staff Bridge
Steven Griffin – Region 4, Hydraulics Engineer
Long Phan – Region 4, Hydraulics
Ina Zisman – Region 4, Traffic Engineer
Dennis Allen – Region 4, Region Maintenance Superintendent
Nicholas A. Stermer – Region 4, Maintenance
Al Roys – Region 4, Maintenance
Vicky Siphler – Region 4, Maintenance
Grant Fisher – Region 4, Maintenance
Brett Locke – Region 4, Resident Engineer
Dawn Walker – Region 4, Maintenance

Table of Contents

1 INTRODUCTION

1.1 Bridge Characteristics and Location

The Colorado Department of Transportation (CDOT) Structure E-15-AH is a single span, steel stringer with metal plank floor, bridge. Structure E-15-AH is located in Boulder County where State Highway 170 crosses over South Boulder Creek. Table 1 presents the bridge characteristics.

Table 1
Bridge Characteristics for E-15-AH

Structure Number	E-15-AH
CDOT Region	4
County	Boulder
Feature Intersected	South Boulder Creek
Facility Carried	SH 170 ML
Mile Marker	0.4
Year Built	1930
ADT (2008)	99
Width (ft.)	16.5
Length (ft.)	41.0
Bridge Spans	1
Number of Piers	0

South Boulder Creek flows from the west to the east through the bridge section. According to the SIA report, this structure is a single span bridge. Historically, a center pier was attached to the bridge, but has since been abandoned and is not considered part of the active structure anymore, but still exists in the channel. Figure 1 and Figure 2 show the vicinity map and an aerial view of the area surrounding the structure, respectively. Figure 3 shows the downstream view of the bridge.

Figure 1
Vicinity Map (Google Earth 2012)

Figure 2
Aerial Image of E-15-AH (Google Earth 2012)

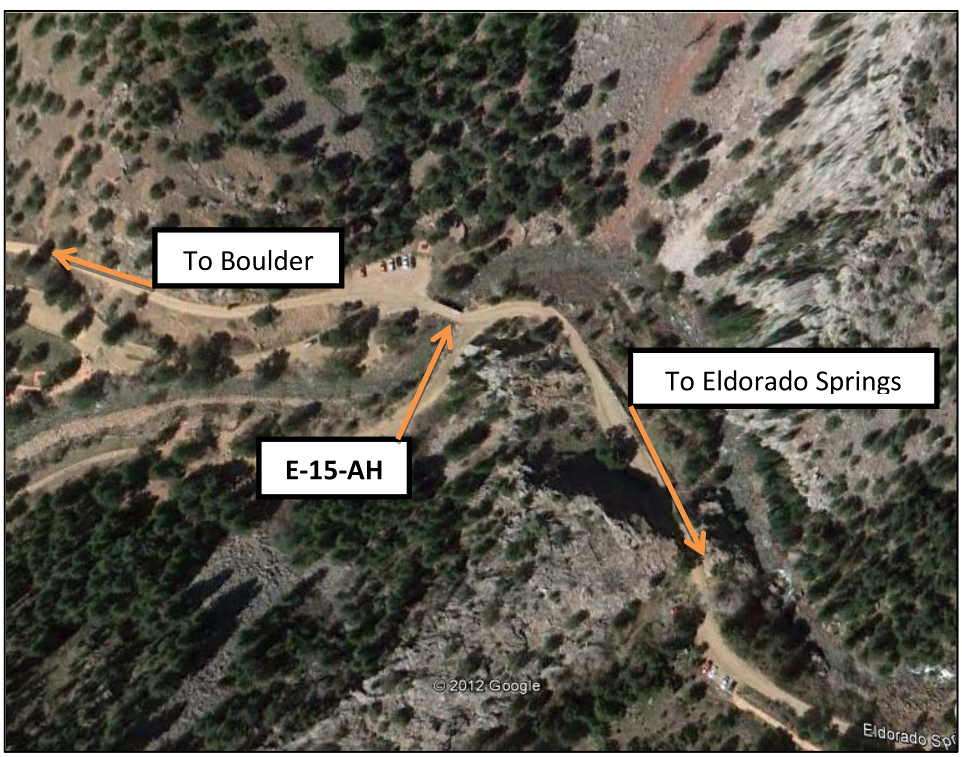


Figure 3
Looking toward the downstream face of the structure

1.2 Scour Condition and Item 113 Code

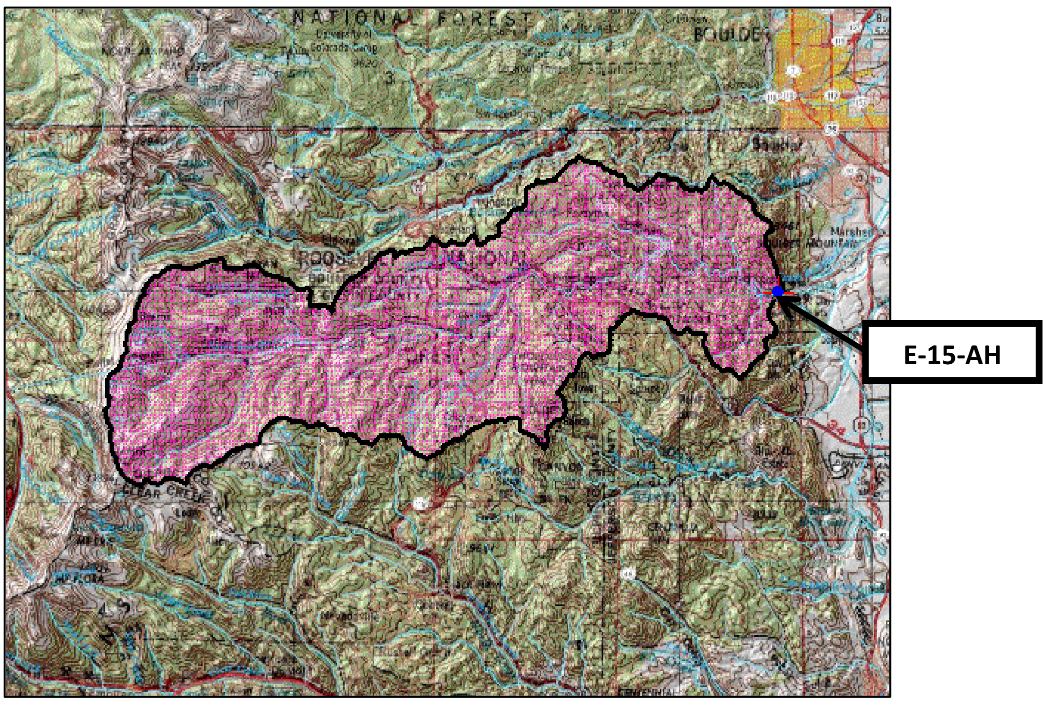
According to earlier Colorado Department of Transportation analysis, the NBI Item 113 Code for Structure E-15-AH is a U. An Item 113 Code U means that the bridge foundations are unknown and the bridge has not been evaluated for scour.

2 HYDROLOGY

2.1 Summary of Peak Flows

South Boulder Creek has a drainage area of 111 square miles at Structure E-15-AH on State Highway 170. The watershed is located 88% in the mountain hydrologic region and 12% is in the plains hydrologic region with 88% of the basin being above 7,500 feet elevation. The mean basin elevation is 9,030 feet and the mean annual precipitation is 25.85 inches. Figure 4 provides an aerial depiction of the drainage basin at Structure E-15-AH over South Boulder Creek. The Colorado StreamStats program was used to obtain the watershed characteristics parameters and peak flow estimates for flood frequency analysis.

Figure 4
Drainage Basin at E-15-AH



The peak discharges for South Boulder Creek at Structure E-15-AH are provided in Table 2. The 100-year flood peak discharge is 1,820cfs and the 500-year peak discharge is 2,500cfs. The USGS Colorado StreamStats peak flow estimates were selected for bridge hydraulic and bridge scour analysis.

Table 2
Summary of Peak Discharges

Flooding Source and Location	10-year (cfs)	50-year(cfs)	100-year (cfs)	500-year (cfs)
South Boulder Creek at SH 170	1,020	1,540	1,820	2,500

3 BRIDGE HYDRAULIC ANALYSIS

3.1 Source of Mapping and Hydraulic Model

The peak discharges presented in Table 2 were used in the hydraulic analysis. Hydrau-Tech, Inc. conducted a survey in August of 2012 which provided topographic data for construction of a hydraulic model. During this topographic survey, seven cross-sections were measured. The locations of the surveyed cross-sections are shown in Figure 5.

Figure 5
Location of surveyed cross-sections at the E-15-AH bridge site

A HEC-RAS hydraulic model was developed using the elevation data collected, along with relevant roughness values and energy loss coefficients derived from the existing conditions observed during the site visit.

3.2 Floodplain Characteristics

There are no FEMA mapping studies for South Boulder Creek in Boulder County near Structure E-15-AH; therefore, a FEMA FIRMette map could not be provided. The floodplain of South Boulder Creek at Structure E-15-AH is very narrow and consists of large boulders and trees. The stream channel itself consists of mostly large boulders to medium cobbles.

3.3 Hydraulic Model Results

Hydrau-Tech, Inc. obtained detailed topographic information needed for the hydraulic modeling through a site visit and a survey of four cross-sections upstream and three cross-sections downstream from the bridge site. These seven cross-sections were then put into the HEC-RAS program to produce the water surface profile and bridge hydraulics. This modeling provided the hydraulic data necessary for scour analysis.

Hydraulic analysis of Structure E-15-AH over South Boulder Creek was performed using HEC-RAS Version 4.1.0. For Structure E-15-AH contraction and expansion loss coefficients were chosen as 0.3 and 0.5, respectively. The selection of higher values for these loss coefficients is due to higher energy losses at the entrance and exit of the bridge site experiencing contracting and expanding flow. The cross-section orientation is looking downstream. The peak discharges for the 100-year and 500-year events presented in the Hydrology section of this report were used in hydraulic modeling. The results of this model are presented in Appendix F. The results for the 500-year event are summarized below in Table 3.

Table 3
Summary of Hydraulics – 500-Year Event

Section	Q (cfs)	WSEL (ft)	Velocity (ft/sec)	Flow Area (sq ft)	Top Width (ft)	Froude Number
319	2500.00	6042.90	7.84	427.36	130.84	0.59
293	2500.00	6043.09	5.84	589.88	170.43	0.41
214	2500.00	6042.90	6.76	530.29	89.36	0.42
141	2500.00	6042.05	9.38	356.87	54.95	0.54
122	Bridge E-15-AH					
80	2500.00	6037.63	13.45	217.09	46.57	0.94
70	2500.00	6036.86	12.74	234.42	55.89	0.97
0	2500.00	6035.21	11.35	235.59	65.67	0.97

4 SCOUR ANALYSIS & RESULTS

4.1 Site Geology

Structure E-15-AH is situated over a boulder and cobble-bed stream. Surface materials in the channel are mostly medium cobbles and boulders. No CDOT as-built drawings were available therefore there is no indication what material the foundations are set on.

4.2 Scour Parameters

As recommended by HEC-18, long-term stream degradation, contraction scour, pier scour, and abutment scour were assessed for the bridge. The median bed material size (D_{50}) for the subsurface material was field-determined to be 152.4mm. The following sections describe the development of the equation parameters for each type of scour.

4.2.1 Stream Degradation

CDOT has been taking streambed measurements at Structure E-15-AH since 1997. The depth measurements taken by CDOT for the abutments, piers, and the channel between the bridge elements are presented in Appendix C. As shown in Appendix C, the channel has experienced both degradation and aggradation of about 1 foot in the past. Because of this fluctuation in measurements, it can be said that the long term degradation of the channel is unknown according to CDOT's streambed measurements.

4.2.2 Contraction Scour

The parameters used in the contraction scour equations were determined from existing work maps and by running the 500-year flood event through the HEC-RAS model. Section 141, which is located approximately 19 feet upstream from Structure E-15-AH, was chosen as the approach cross-section. This section accurately represents the general channel geometry upstream from the bridge, and it was compared to the contracted bridge cross-section to determine the magnitude of the contraction scour.

Based on average velocity and critical velocity calculations in the approach cross-section, the clear-water contraction scour equation was used for the main channel. The width for the approach cross-section was defined as the bottom width of the channel. For the contracted bridge cross-section, the bottom deck width was used for the channel width. These widths are intended to reflect the portions of the channel which are actively mobilizing sediment. The flow area and channel flows were determined from the flow distribution within the channel widths.

Table 4 summarizes the parameters used to calculate the contraction scour for Structure E-15-AH. Variables with a subscript of 1 indicate the stream approach cross-section and variables with a subscript of 2 indicate the contracted bridge cross-section. Complete scour calculations are presented in Appendix G.

Table 4
Contraction Scour Parameters – 500-Year Event

Flow Area		Channel Flow		Channel Width		EG Slope	Correction Factor
A_1 (ft^2)	A_2 (ft^2)	Q_1 (cfs)	Q_2 (cfs)	W_1 (ft)	W_2 (ft)	S_1 (ft/ft)	K_1
210.3	248	1971.6	2500	22.3	37	0.0093	0.64

4.2.3 Pressure Scour

Pressure scour does not occur at Structure E-15-AH.

4.2.4 Pier Scour

The parameters used in the pier scour equations were determined from as-built drawings and photos and by running the 500-year event in the HEC-RAS model. The flow depth and velocity from flow distributions, as generated by HEC-RAS, were used for the flow directly upstream from the pier. The most conservative values were chosen for the K_2, K_3, and K_4 correction factors in the pier scour equation. A value of 0.9 was chosen for K_1 due to the sharp-nosed pier at Structure E-15-AH. The correction factors and other parameters used to calculate pier scour are presented in Table 5.

Table 5
Pier Scour Parameters – 500-Year Event

Pier	Flow Depth Y_1 (ft)	Pier Width a (ft)	Mean Velocity V_1 (ft/s)	Froude Number F_r	Correction Factors			
					K_1	K_2	K_3	K_4
2	9.7	3.0	8.5	0.48	0.9	1.0	1.1	1.0

4.2.5 Abutment Scour

Velocity, depth, and area for the flow obstructed by the abutments were computed in order to calculate abutment scour. For Structure E-15-AH, the abutment location was projected to upstream Section 141 in the HEC-RAS model, and flow distribution tables were used to find the resulting parameters. Table 6 shows the parameters used to calculate the abutment scour for the 500-year event. Complete scour calculations are presented in Appendix G.

Table 6
Abutment Scour Parameters – 500-Year Event

Abutment	Θ (deg)	L (ft)	L' (ft)	A_e (ft^2)	Q_e (cfs)
Left (1)	90	50	9.6	54.0	193.2
Right (3)	90	3.9	3.9	2.8	3.6

4.3 Scour Results

The results of the scour analysis for the 500-year event are summarized in Table 7. Figure 6 presents the theoretical scour depths from a profile view of the bridge. Detailed scour calculations are located in Appendix G.

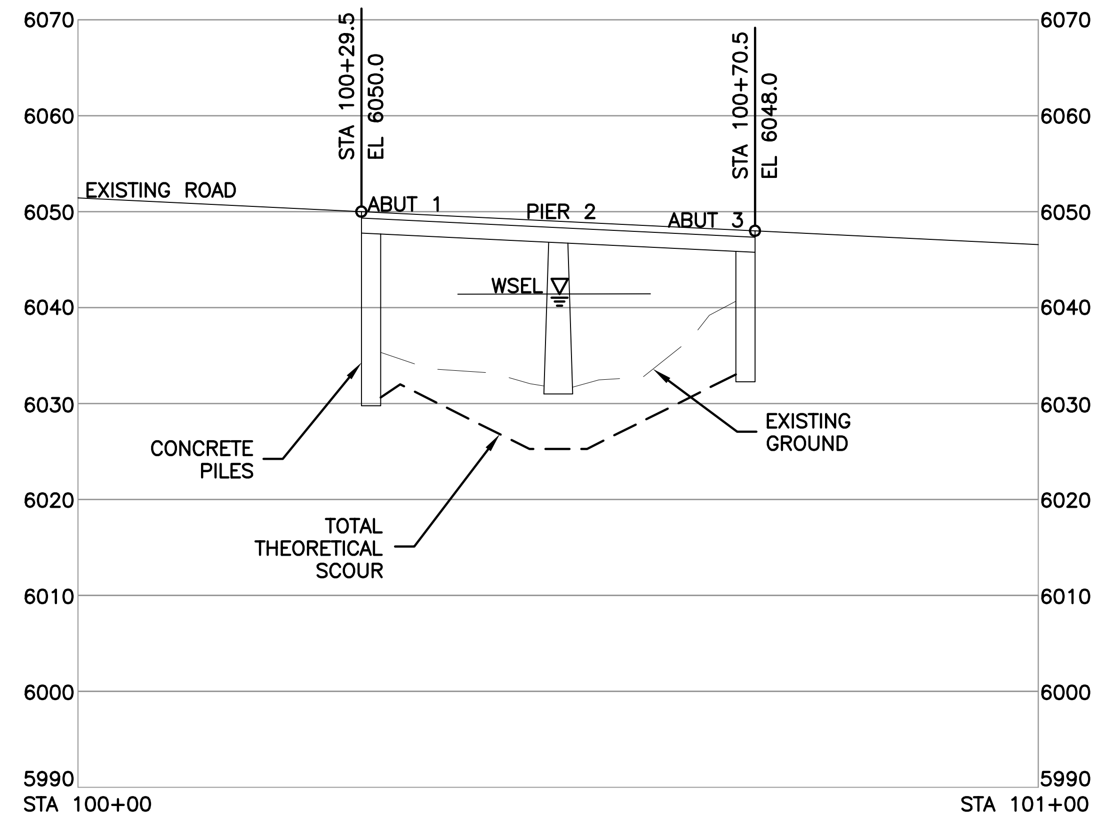
Table 7

Summary of Scour Results – 500-Year Event

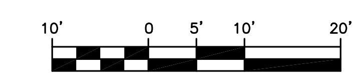
Scour Component	Long Term Degrada-tion	Contraction			Pier Scour	Abutment Scour	
		Left Overbank	Main Channel	Right Overbank	2	Left	Right
	0.0	0.0	0.0	0.0	6.5	4.7	2.0
Total Scour (ft)					6.5	4.7	2.0

E-15-AH SCOUR PLOT

Scour Summary									
			Long Term Aggradation/	Contraction			Abutment		Pier
Event	Discharge	WSEL	Degradation	Left	Channel	Right	Left (1)	Right (3)	2
500-Yr	2500 cfs	6041.41	0.0'	0.0'	0.0'	0.0'	4.7'	2.0'	6.5'



E–15–AH OVER S. BOULDER CREEK
LOOKING DOWNSTREAM



HORIZ. SCALE: 1"=20'
VERT. SCALE: 1"=20'

NOTES:
1. TOTAL SCOUR IS THE SUMMATION OF: CONTRACTION SCOUR + ABUTMENT SCOUR + PIER SCOUR + LONG TERM AGGRADATION/DEGRADATION SCOUR AS PER FHWA EQUATIONS USING SANDBED.
2. GEOLOGY INFORMATION SHOWN WAS OBTAINED FROM AS–BUILT BRIDGE PLANS.
3. STATIONING INFORMATION SHOWN WAS OBTAINED FROM AS–BUILT BRIDGE PLANS.

VERTICAL DATUM SHOWN = NAVD 88

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PLOT DATE: Jun 04, 2013 4:07pm

Print Date: Jun 04, 2013 4:07pm

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Sheet Revisions		
Date:	Comments	Init.

Colorado Department of Transportation
4201 East Arkansas Ave
Denver, CO 80222
Phone: 303–757–9044
Headquarters AM

As Constructed
No Revisions:
Revised:
Void:

E–15–AH
SCOUR PLOT

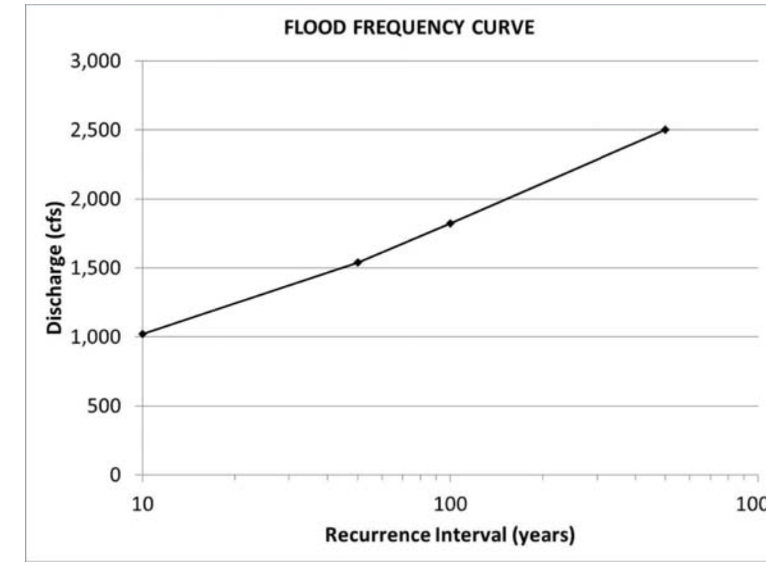
Designer: A. MOLINAS | Structure Numbers: E–15–AH
Detailer: SOLLENBERGER
Sheet Subset: | Subset Sheets: 10 of 13

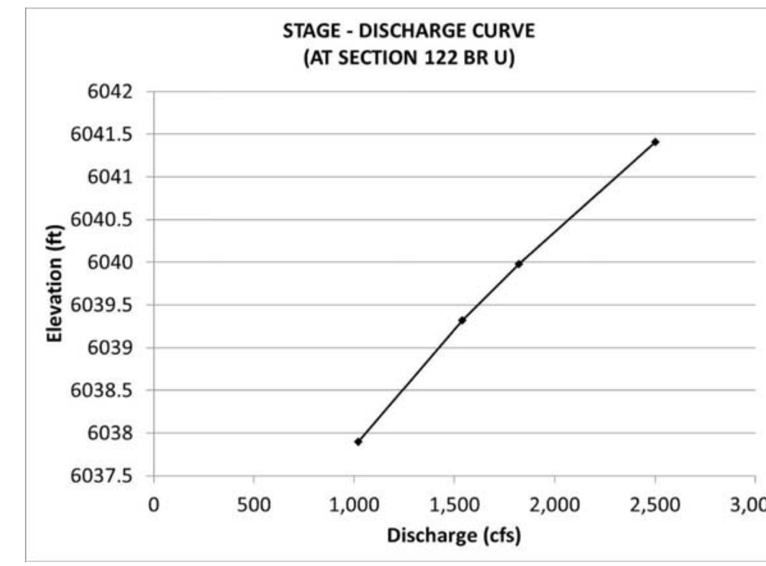
FIGURE
6

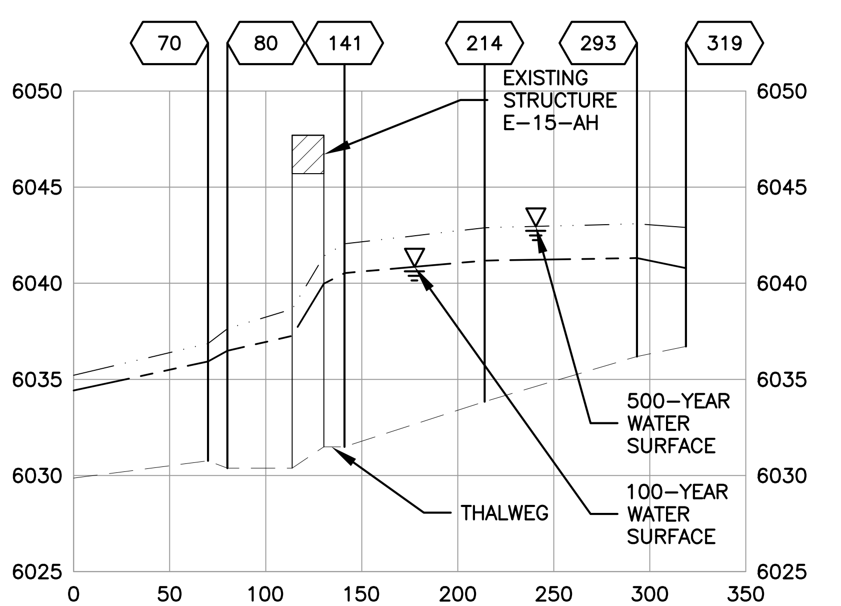
PRELIMINARY
NOT FOR CONSTRUCTION

PLAN VIEW FOR E-15-AH
OVER S BOULDER CREEK

HEC-RAS STATIONING



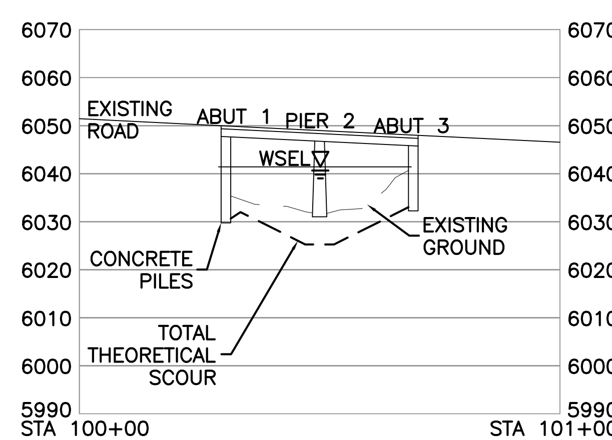




E-15-AH PROFILE

ORIGINAL SCALE
HORIZ. SCALE: 1"=100'
VERT. SCALE: 1"=10'

Scour Summary									
Event	Discharge	WSEL	Long Term Aggradation/ Degradation	Contraction			Abutment		Pier
				Left	Channel	Right	Left (1)	Right (3)	2
500-Yr	2500 cfs	6041.41	0.0'	0.0'	0.0'	0.0'	4.7'	2.0'	6.5'



E-15-AH OVER S. BOULDER CREEK
LOOKING DOWNSTREAM

ORIGINAL SCALE
HORIZ. SCALE: 1"=40'
VERT. SCALE: 1"=40'

NOTE: THIS DRAWING IS FOR PLANNING PURPOSES AND REPRESENTS CONCEPTUAL ENGINEERING. ALTERNATIVES WILL BE CONSIDERED BY CDOT PROVIDED THE ALTERNATIVE OFFERS AN EQUIVALENT INTENT OF THE PLAN. THIS DRAWING DOES NOT PROVIDE A PRELIMINARY OR FINAL DESIGN AND SHALL NOT BE USED FOR CONSTRUCTION PURPOSES.

VERTICAL DATUM SHOWN = NAVD 88

NAME: E:\POA\POA 4 2013\E-15-AH South Boulder Creek\E-15-AH CAD\E-15-AH_DRAFT.dwg
PLOT DATE: Sep 09, 2013 3:04pm

Print Date: Sep 09, 2013 3:04pm

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Sheet Revisions		
Date:	Comments	Init.

Colorado Department of Transportation
DOT
4201 East Arkansas Ave
Denver, CO 80222
Phone: 303-757-9044
Headquarters AM

As Constructed
No Revisions:
Revised:
Void:

E-15-AH
BRIDGE HYDRAULIC INFORMATION
HYDRAULIC SUMMARY

Designer:	A. MOLINAS	Structure Numbers	E-15-AH
Detailer:	SOLLENBERGER		
Sheet Subset:		Subset Sheets:	11 of 13

FIGURE 7

4.4 Bridge Stability Analysis

The computed scour for the 500-year flow event for Structure E-15-AH shows significant scour at the pier. However, the pier is not structurally connected to the bridge itself, it is still blocking flow in the bridge section and will therefore still cause scour. The bridge will most likely not fail under the conditions of the 500-year flow event. The theoretical scour goes to the abutment foundations. However, previously placed rip-rap along with rocks in the stream bed will protect the abutments.

4.5 Updated Item 113 Code

The NBI 113 Code for Structure E-15-AH is currently a U (Unknown foundations). Hydrau-Tech, Inc. obtained basic bridge geometry information from the SIA report and field measurements and channel geometry estimations from a survey of seven cross-sections. This information was used in conducting the hydraulic and scour analysis. Pile and foundation depths were determined by Olson Engineering through Sonic Echo testing. These test results were presented in a report by Olson Engineering and were used to determine the stability of the structure given the occurrence of the preliminary theoretical scour. The report conducted by Olson Engineering can be found in Appendix B.

We propose that the Item 113 Code for Structure E-15-AH be changed from a U to an 8. An Item 113 code of 8 means bridge foundations have been determined to be stable for calculated scour conditions; calculated scour is above the bottom of the footings. The field conditions at Structure E-15-AH showed the following:

1. The theoretical scour from the 500-year event is above the estimated footing depths.
2. The abutments have sufficient sized riprap protection to prevent abutment scour as shown in Figure A7 and A8.
3. The channel bed is comprised of cobbles and boulders and will help protect the channel bed and abutments during high flow events as shown in Figure A3.

Based on our computations and interpretations of field conditions, we propose that the current NBI Item 113 Code of U be changed to an 8 and Structure E-15-AH be taken off the scour critical bridge list.

5 REFERENCES

"Hydraulic Engineering Circular No. 18 – Evaluating Scour at Bridges – Fourth Edition," U.S. Department of Transportation, Federal Highway Administration, May 2001.

"Hydraulic Engineering Circular No. 23 – Bridge Scour and Stream Instability Countermeasures: Experience, Selection, and Design Guidance – Third Edition," U.S. Department of Transportation, Federal Highway Administration, September 2009.

National Oceanic and Atmospheric Administration, National Weather Service. NWS Internet Services Team "Watches, Warnings or Advisories for Colorado"
http://alerts.weather.gov/cap/co.php?x=1

United States Geological Survey-USGS, Colorado StreamStats.
http://water.usgs.gov/osw/streamstats/colorado.html

Appendix A – Site Review and Photos

Figure A.1.
Looking toward the structure entrance

Figure A.2.
Looking toward the structure outlet

Figure A.3.
Looking toward South Boulder Creek upstream from the structure

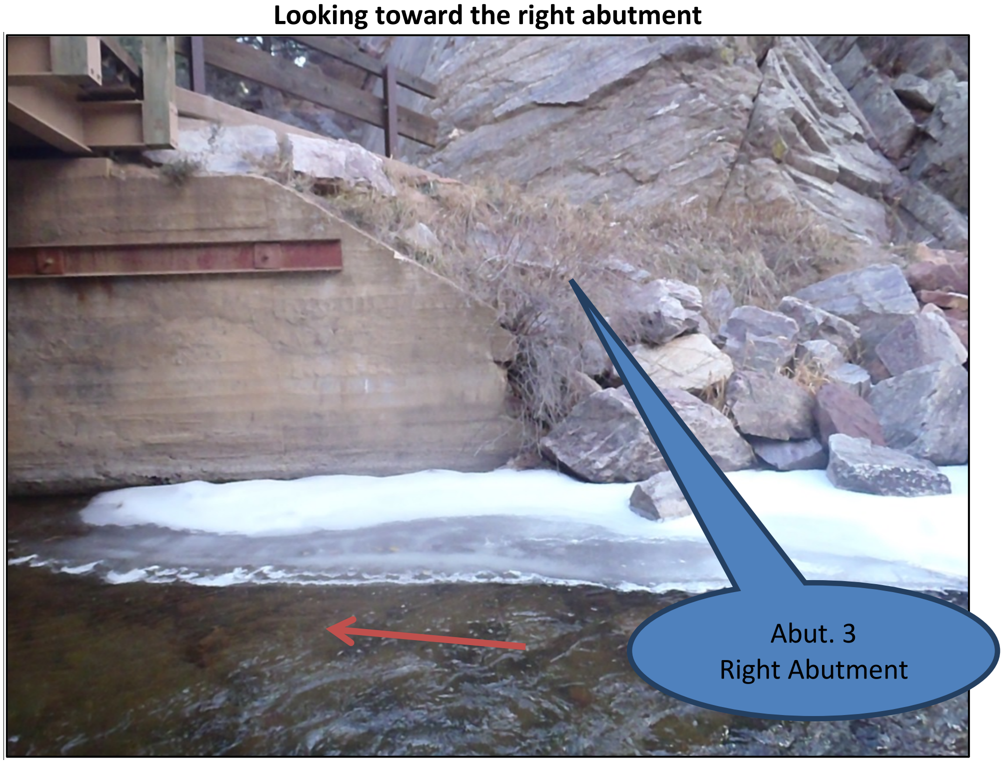
Figure A.4.
Looking toward South Boulder Creek downstream from the structure

Figure A.5.
Roadway looking toward increasing roadway station

Figure A.6.
Roadway looking toward decreasing roadway station

Figure A.7.
Looking toward the left abutment

Figure A.8.
Looking toward the right abutment



Appendix B – Existing Bridge Plans & Subsurface Information

INFRASTRUCTURE IMAGING AND NDE
ASSESSMENT, MONITORING AND REPAIR

Olson ENGINEERING

Corporate Office:
12401 W. 49th Ave.
Wheat Ridge, CO 80033-1927 USA
phone: 303.423.1212
fax: 303.423.6071

Moser & Associates Engineering
720 S. Colorado Boulevard, Suite 410S
Denver, CO 80246

Attn: Mr. Rick Moser

Office: (303)757-3655
E-mail: moser@moser-eng.com

RE: Unknown Bridge Foundation Depth Investigation
Ultraseismic and Sonic Echo Testing
CDOT Bridge Number E-15-AH
Boulder County, Colorado
Olson Job No. 3642B

Gentlemen:

This report presents the results of Nondestructive Testing (NDT) performed on two foundation walls for Moser & Associates Engineering on CDOT bridge number E-15-AH in Boulder County, Colorado. The testing was performed on August 10, 2011 by Mr. Dennis Sack, Senior Vice President and Associate Engineer, Mr. Colin Leek, Project Engineer, and Ms. Lorae Tracy, Engineering Technician of our firm. The testing was performed with the Sonic Echo/Impulse Response (SE/IR) accompanied by the Ultraseismic (US) test method.

TESTING PROCEDURES AND LOCATIONS

US data were only collected on the West foundation wall for SE/IR data comparison and quality control purposes. The US data were collected by grease mounting a vertical accelerometer (mounted on a small aluminum block) to the side of the vertical wall to monitor the reflection of a compressional wave generated by impacting the top of the foundation wall with a 3-lb instrumented sledgehammer. The hammer input and receiver outputs from the many receiver locations (spaced evenly 12 inches apart down the side of the wall) were recorded by an Olson Instruments NDE360. The recorded receiver outputs were then analyzed in a seismic analysis software package (IX Foundation) and were stacked together much like the stacking of geophysical data. The stacking of these traces allowed for tracking of the reflected waves. In addition, the slope of coherent events in the stacked records helped to determine the velocity of the direct and reflected waves to be used in the depth calculation.

The Sonic Echo test method was also employed in this investigation on both the West and East foundation walls by mounting a single component accelerometer in a vertical orientation on the top of the respective foundation wall. A compressional wave was again generated by impacting the top of the foundation wall with a 3-lb instrumented sledgehammer (Figure 1). For the walls tested in this investigation, a representative measured compression wave velocity of 12,000 feet per second (fps) was used to compute the reflector depth which is nominally a typical velocity for concrete. It is estimated that predicted depths are accurate to within about 10% of actual values. Technical briefs describing both the Ultraseismic and Sonic Echo test methods are included in Appendix A.

TESTING RESULTS

The stacked plots for the collected US data for the West foundation wall are presented below in Figure 2. The slope of the highlighted coherent events in the stacked records determined the velocity of the direct and reflected waves used to calculate the shown pile depth. US testing on the West foundation wall showed a pile length of 16.5 ft. This depth is referenced from the top of the foundation wall.

The Sonic Echo (SE/IR) test results indicated the pile lengths, referenced from the top of the foundation wall, to be 18.2 feet for the West foundation wall and 13.7 feet for the East foundation wall. The SE plots from the SE/IR test results for these foundation walls are presented below in Figures 3 and 4. The SE/IR plots presented in this report are taken from a multitude of SE/IR test records from each pile to show the representative, average measured pile length.

Figure 1 – SE/IR Testing from the top of the East foundation wall.

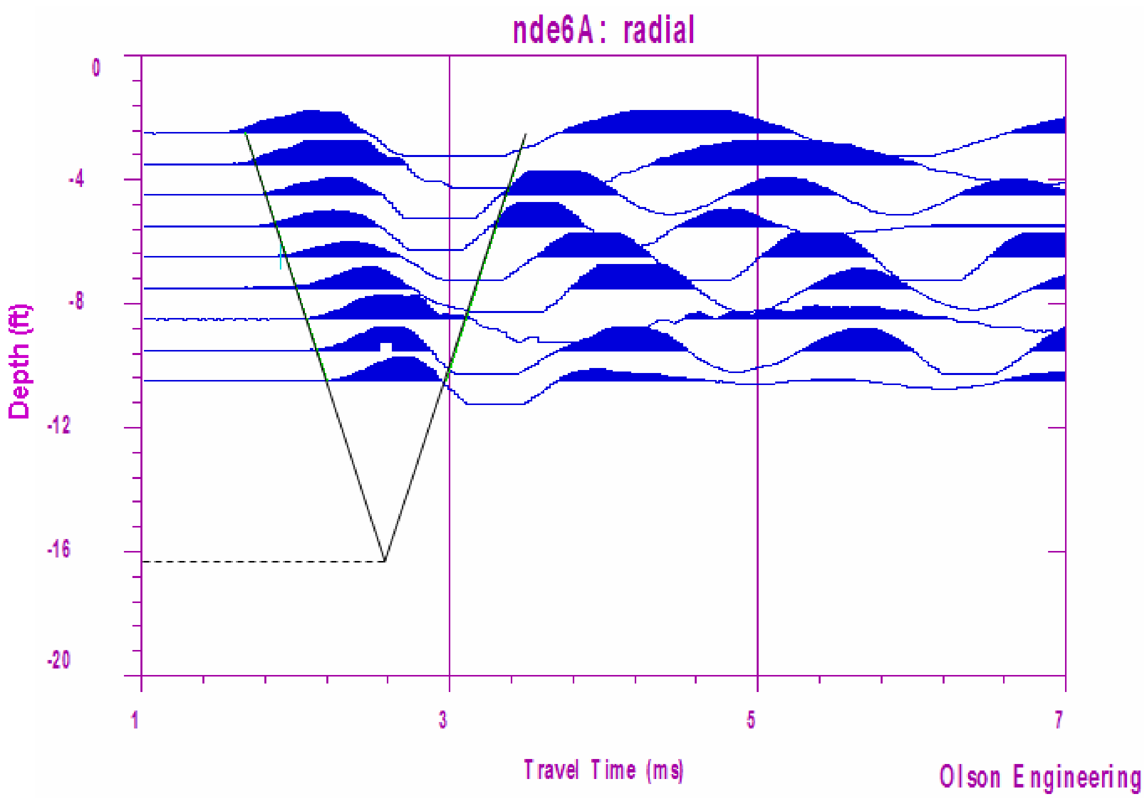


Figure 2 – US data collected from Boulder county bridge number E-15-AH, West foundation wall. Apparent length is approximately 16 ½ feet.

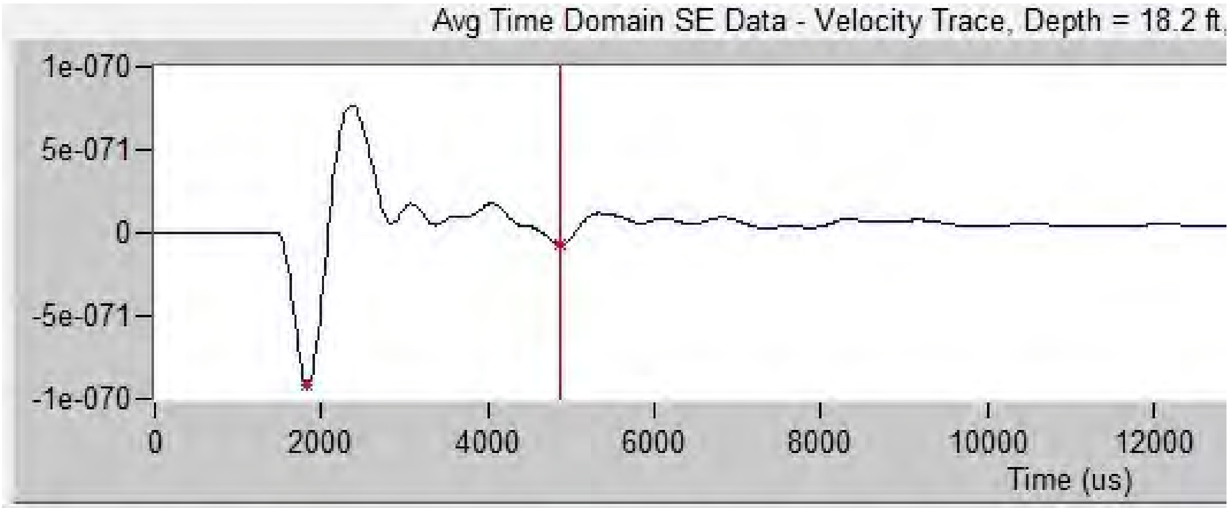


Figure 3 - Sonic Echo data collected from Boulder county bridge number E-15-AH, second West foundation wall test. Apparent length = 18.2 feet (from top of foundation wall).

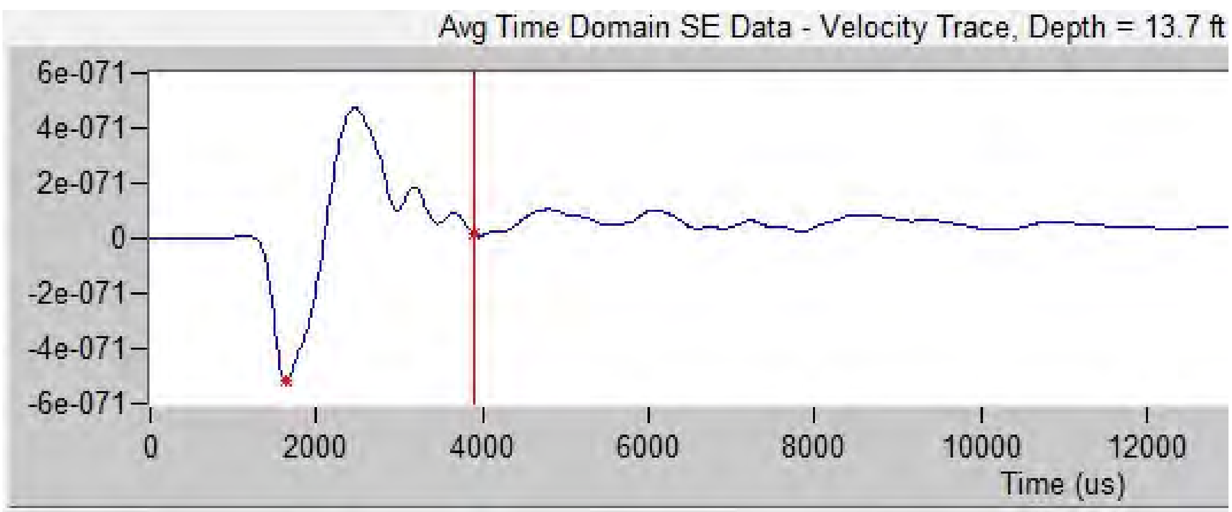


Figure 4 - Sonic Echo data collected from Boulder county bridge number E-15-AH, second East foundation wall test. Apparent length = 13.7 feet (from top of foundation wall).

CONCLUSIONS

An approximate foundation wall total height of 18 feet was measured for the West foundation wall and an approximate foundation wall height of 13 ½ feet was measured for the East foundation wall at Boulder county bridge E-15-AH. The West foundation wall height was determined by comparing the SE/IR data with the US results. The US results concluded to be less accurate then the SE/IR data due to in-situ field conditions and overall data quality. Thus only SE/IR data were collected for the East foundation wall. During data acquisition, the West foundation wall had approximately 10 ½ feet of exposed wall above grade/stream level and the East foundation wall had approximately 8 feet of exposed wall. Based on these data the West foundation wall extended 7 ½ feet into the ground and the East foundation wall extended 5 ½ feet into the ground at the time of acquisition.

A sketch of the bridge components as observed at the time of testing as well as measured with the NDE investigation is presented below in Fig. 5. As seen, the sketch includes the measured height of the abutment walls above local grade and below the bridge deck , as well as the measured depth of penetration into the subgrade of the foundation walls.

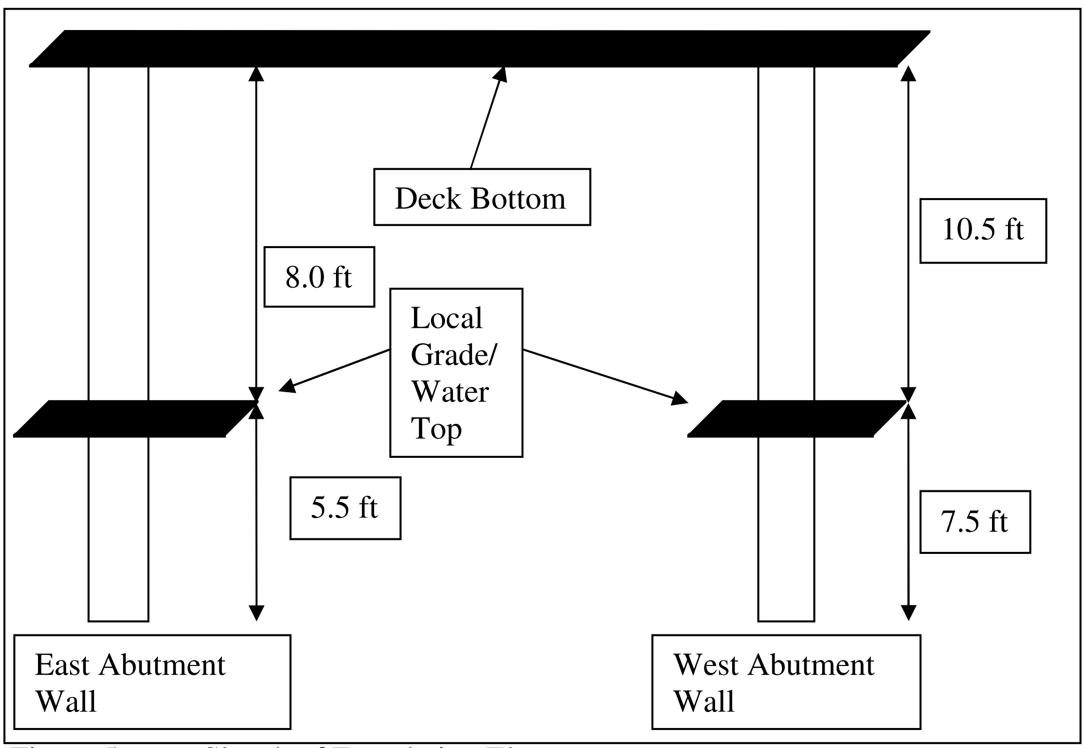


Figure 5 Sketch of Foundation Elements

Photos of the bridge elements are presented in Figs. 6-8.

Figure 6 View to West Abutment Wall (Note – visible center pier is abandoned and is not part of the active structure)

Figure 7 View to East Abutment Wall (Note – visible center pier is abandoned and is not part of the active structure)

Figure 8 Close-up View of West Abutment Wall

CLOSURE

The field portion of this NDT investigation was performed in accordance with generally accepted testing procedures. If we can provide additional information or services on this project, or additional information becomes available that would impact the findings of this investigation, please call.

Respectfully submitted,

OLSON ENGINEERING, INC.

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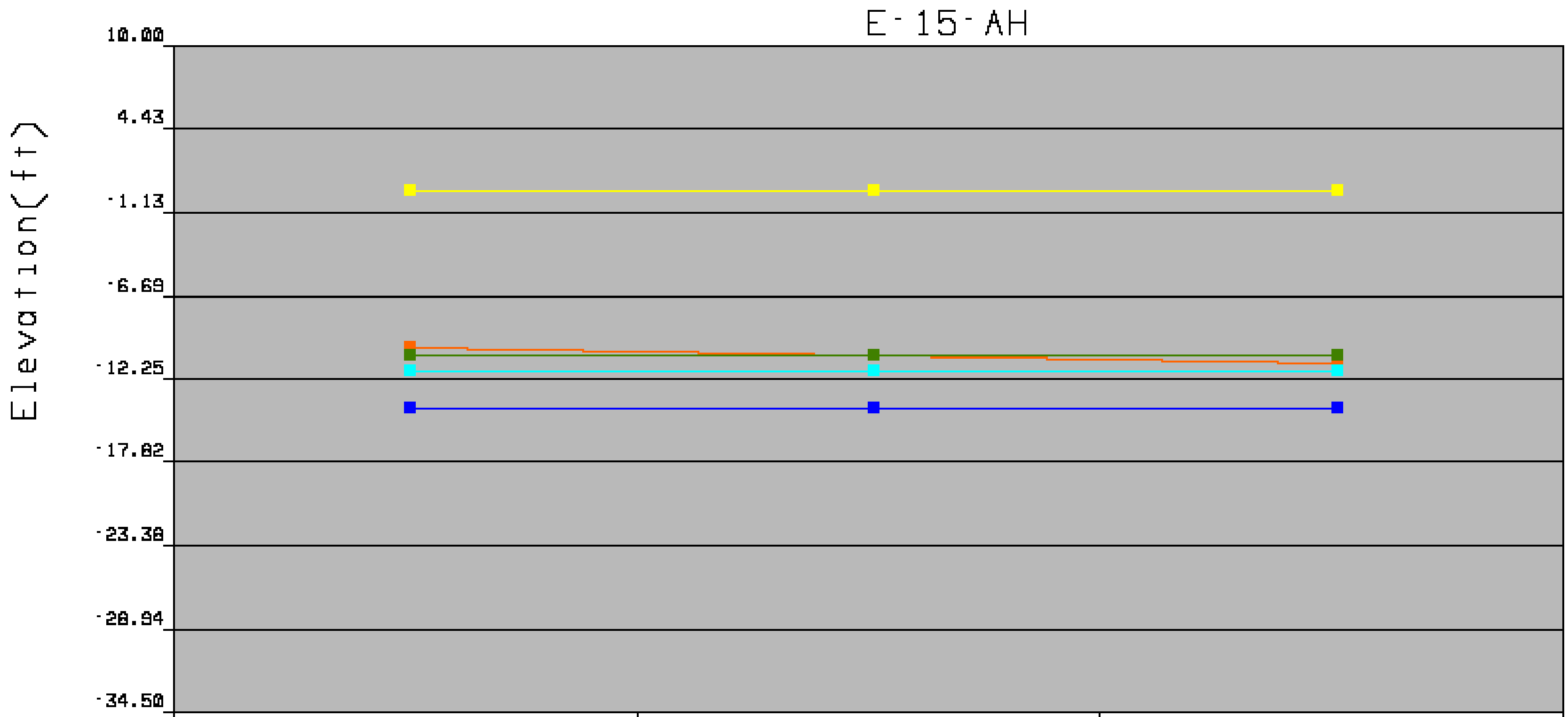
Colin O. Leek
Project Engineer

____
Dennis A. Sack, P.E.
Senior Vice President, Associate Engineer

(2 copies mailed)
(1 copy e-mailed)

APPENDIX A

Appendix C – CDOT Inspection Information



1930 GUESS FOOTING	-14.50	-14.50	-14.50
500 YR SCOUR	-12.00	-12.00	-12.00
2008	-11.00	-11.00	-11.00
2005	0.00	0.00	0.00
2003	-10.41	-11.00	-11.41
2001	0.00	0.00	0.00
1997	0.00	0.00	0.00

Appendix D – 1990's CDOT & USGS Analysis

Colorado Department of Transportation
Structure Inspection and Inventory Report (English Units)

Bridge Key: E-15-AH | Inspection Date: 9/15/2009 | Sufficiency Rating: 74.2 FO

Rgn/Sectn 2E/2M:	41
Trans Region 2T	02
County Code 3:	013
BOULDER	
Place Code 4:	00000
non-city	
Rte.(On/Under)5A:	1
Signing Prefix 5B:	7
Level of Service 5C:	1
Directional Suffix 5E:	0
Feature Intersected 6:	
SOUTH BOULDER CREEK	
Facility Carried 7:	
SH 170 ML	
Alias Str No.8A:	
Prll Str No. 8P	
Location 9:	
0.9 MI W. OF EL DORADO SP	
Max Clr 10:	99.99
BaseHiway Net12:	0
IrsinvRout 13A	0000000000
IrssubRout No13B:	00
Latitude 16:	39d 55' 51"
Longitude 17:	105d 17' 29"
Range18A:	71 W
Township18B:	71
Section18C:	25
Detour Length 19:	2.0 mi
Toll Facility 20:	3
Custodian 21:	1
Owner 22:	11
Functional Class 26:	09
Year Built 27:	1930
Lanes on 28A:	1
Lanes Under 28B:	0
ADT 29:	99
Year of ADT 30:	2008
Design Load 31:	0
Apr Rdwy Width 32:	15.0 ft
Median 33:	0
Skew 34:	10.00 °
Structure Flared 35:	0
Sfty Rail 36a/b/c/d:	0 0 0 0
Rail ht36h:	42 "in"

Hist Signif 37:	5
Posting status 41:	A
Service on/un 42A/B:	1 5
Main Mat/Desgn 43A/B:	3 2
Appr Mat/Desgn 44A/B:	0 0
Main Spans Unit 45:	1
Approach Spans 46:	0
Horiz Clr 47:	16.0 ft
Max Span 48:	37.0 ft
Str Length 49:	41.0 ft
Curb Wdth L/R 50A/B:	0.0 ft 0.0 ft
Width Curb to Curb 51	16.0 ft
Width Out to Out 52:	16.5 ft
Deck Area:	677. sq. ft
Min Clr Ovr Brdg 53:	99.99
Min Undrclr Ref 54A:	N
Min Undrclr 54B:	0.0 ft
Min Lat Clrnce Ref R 55A:	N
Min Lat Undrclr R 55B:	0.0 ft
Min Lat Undrclr L 56:	0
Deck 58:	6
Super 59:	6
Sub 60:	6
Channel/Protection 61:	8
Culvert 62:	N
Oprtng Rtg Method 63:	1 LF Load Factc
Operating Rating 64:	40.0
Inv Rtng Method 65:	1
Inventory Rating 66:	24.0
Asph/Fill Thick 66T:	000 "in"
Str. Evaluation 67:	6
Deck Geometry 68:	3
Undrclr Vert/Hor 69:	N
Posting 70:	5
Waterway Adequacy 7	8
Approach Alignment 72:	6
Type of Work 75A:	33
Work Done By 75B:	1
Length of Improvment 76:	41.0 ft
Insp Team Indicator 90B:	White Team (Ric
Inspector Name 90C:	CHURCHESK
Frequency 91:	24 months
FC Frequency 92A:	-1
UW Frequency 92B:	-1
SI Frequency 92C:	-1
FC Inspection Date 93A:	

UW Inspection Date 93B	
SI Date 93C:	
Bridge Cost 94:	$ 24,413
Roadway Cost 95:	$ 2,441
Total Cost 96:	$ 36,619
Year of Cost Estimate 97:	2006
Brdr Brdg Code/% 98A/B:	
Border Bridge Number 99:	
Defense Highway 100:	0
Parallel Structure 101:	N
Direction of Traffic 102:	3
Temporary Structure 103	_
Highway System 104:	0
Fed Lands Hiway 105:	0
Year Reconstructed 106	1993
Deck Type 107:	6
Wearing Surface 108A	7
Membrane 108B:	0
Deck Protection 108C:	0
Truck ADT 109:	5 %
Trk Net 110:	0
Pier Protection 111:	#
NBIS Length 112:	Y
Scour Critical 113:	U
Scour Watch 113M:	_
Future ADT 114:	110
Year of Future ADT 115	2028
CDOT Str Type 120A:	SSM
CDOT Constr Type 120B	0.
Inspection Indic 122A:	
Inspection Trip 122AA	
Scheduling Status 122B	
Maintenance Patrol 123:	13
Expansion Dev/Type124	O
Brdg Rail Type/Mod 125A/B	E 2
Posting Trucks 129A/B/C	0 0 0
Str Rating Date 130:	9/24/1996
Special Equip 133:	-1
Vert Clr N/E 134A/B/C:	X 99.99 0.00
Vert Clr S/W 135A/B/C	X 99.99 0.00
Vertical Clr Date:	1/1/1901
Weight Limit Color: 139	0
Str Billing Type:	U
Userkey 1 - System:	ONSYS
Userkey 7-Update Indic	

Inspector Name: CHURCHESK

Colorado Department of Transportation
Structure Inspection and Inventory Report (English Units)

Element Inspection Report

Elm/Env	Description	Units	Total Qty	% in 1	CS 1	% in 2	CS 2	% in 3	CS 3	% in 4	CS 4	% in 5	CS 5
30/1	Corrug/Orthotpc Deck	(SF)	677	100 %	677	0 %	0	0 %	0	0 %	0	0 %	0
107/1	Paint Stl Opn Girder	(LF)	148	0 %	0	50 %	74	49 %	73	1 %	1	0 %	0
215/1	R/Conc Abutment	(LF)	35	100 %	35	0 %	0	0 %	0	0 %	0	0 %	0
310/1	Elastomeric Bearing	(EA)	8	100 %	8	0 %	0	0 %	0	0 %	0	0 %	0
326/1	Bridge Wingwalls	(EA)	4	100 %	4	0 %	0	0 %	0	0 %	0	0 %	0
332/1	Timb Bridge Railing	(LF)	82	100 %	82	0 %	0	0 %	0	0 %	0	0 %	0
501/1	Channel Cond	(EA)	1	100 %	1	0 %	0	0 %	0	0 %	0	0 %	0
504/1	BankCond	(EA)	1	100 %	1	0 %	0	0 %	0	0 %	0	0 %	0

Elem/Env	Description	Element Notes
30/1	Corrug/Orthotpc Deck	4X12 corrugated metal deck (R1 corrosion at bottoms of corrugations), with longitudinal treated timber planks as the riding surface. 3.75 inch thick timber planks are worn up to 2 inches deep in the wheel lines; (see 2005 PHOTOS). Leakage as expected.
107/1	Paint Stl Opn Girder	Light R1 to R1 corrosion on the top and bottom flanges. The paint is starting to peel, primarily along the top flanges. The bottom of the top flange of Girder A, between Abutment 1 and the dead pier, has a 12 inch long area of R2 corrosion. Gravel is spilling around the abutment backwalls at the outside corners, depositing gravel on the bottom flanges of exterior girders.
215/1	R/Conc Abutment	Old concrete with rock pockets, some pockets are patched. Abutment 2 has a 10 inch metal channel mounted horizontally on the abutment and wings, about 8 feet up from the footer, attached by earth anchors. Abutment 2 is pushed, and leans 6 inches for a 6.5 foot height, as measured with a string line and plumb bob from the edge of the steel channel (3 inch flanges). (See 2005 PHOTO and SKETCH) This 4.5 degree lean appears to be stabilized, judging from the position of the bearing bolts relative to the sole plates. Gravel is spilling around the abutment backwalls at outside corners, depositing gravel on the exterior girder bottom flanges.
310/1	Elastomeric Bearing	The bearing under Girder D at Abutment 2, is covered with gravel. Otherwise look OK.
326/1	Bridge Wingwalls	Old concrete with rock pockets. #1 Right wing has some disintegration on the top, with large aggregate exposed, approximately 10 to 20 feet from the bridge. End of #2 Rt. wing is spalling.
332/1	Timb Bridge Railing	Typical checking in rails and posts. Splintered at Abutment 2 end of left rail.
501/1	Channel Cond	South Boulder Creek. Rock and cobble bottom for swift year round flow, alignment OK. The pier in the middle of the channel extends up to within 3 inches of the girders; but does not, and was not intended to support them.
504/1	BankCond	Rocky with willows and trees, some boulders.

Colorado Department of Transportation
Structure Inspection and Inventory Report (English Units)

Maintenance Activity Summary

MMS Activity	Description	Recommended	Status	Target Year	Est Cost
353.02	Replace	2/7/2008	-1	2012	1000

Replace the worn planks on the deck.

MMS Activity	Description	Recommended	Status	Target Year	Est Cost
357.01	Replace	2/7/2008	-1	2012	200

Remove sand and gravel from the bearing areas.

Bridge Notes

Conditions merit high fair or "6" for NBI Items 58, 59, and 60. Per Jeff Anderson 2/6/09

Colorado Department of Transportation
Structure Inspection and Inventory Report (English Units)

Inspection Notes

Temperature: 72 Degrees
Time: 12:20
Weather: Partly Cloudy

Scope:

☑ **NBI:** ☑ **Element:** ☐ **Underwater:** ☐ **Fracture Critical:** ☐ **Other:** **Type:** Regular NBI

Inspector: CHURCHESK **Inspection Team:**

Inspection Date: 09/15/2009

____
Inspector

____
Inspector

Appendix E – Hydrologic Analysis

Drainage Basin at E-15-H (USGS StreamStats)

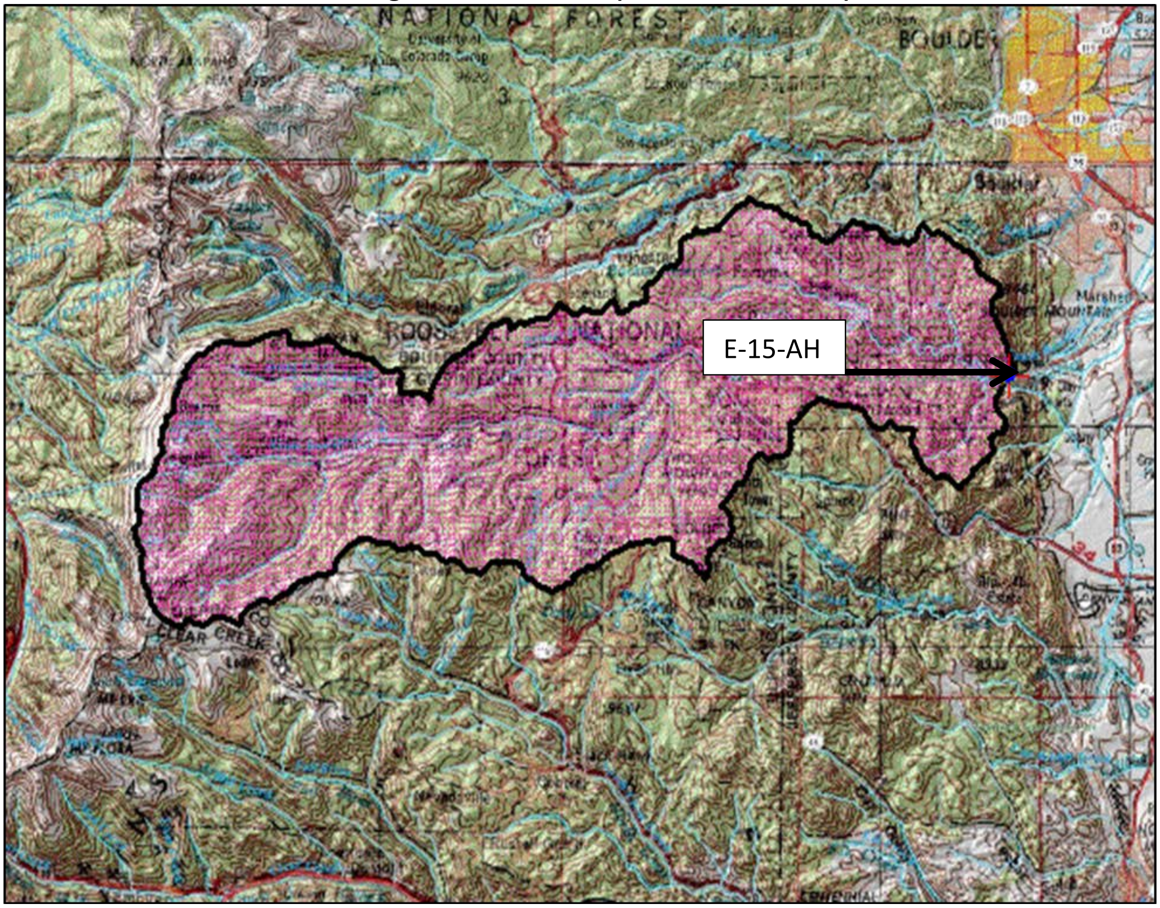


Table E.1.
Basin Characteristics Report (USGS StreamStats)

Parameter	Value
6-hour, 100-year precipitation, in inches	2.98
Mean basin slope computed from 10 m DEM, in percent	29.6
Area that drains to a point on a stream in square miles	111
Mean Basin Elevation in feet	9030
Mean annual precipitation, in inches	25.85
Percentage of basin above 7500 ft elevation	88.3

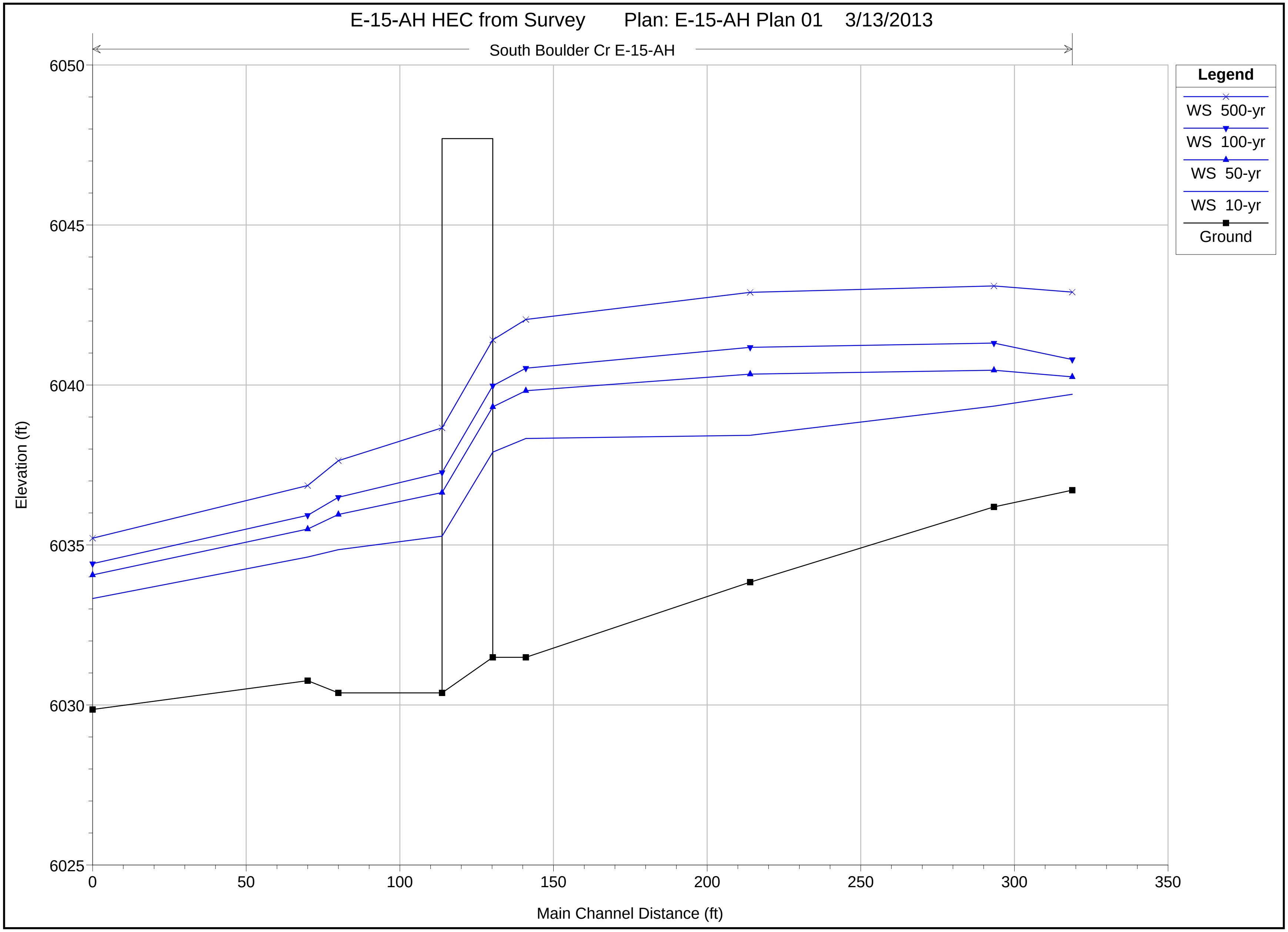
Table E.2.
USGS StreamStats Basin Characteristics

Peak-Flows Basin Characteristics			
88 % Mountain Region Peak Flow (97.3 mi2)			
Parameter	**Value**	**Regression Equation Valid Range**	
		Min	**Max**
Drainage Area (square miles)	111	1	1060
Mean Basin Slope from 10m DEM (percent)	29.6	7.6	60.2
Mean Annual Precipitation (inches)	25.85	18	47
12 % Plains Region Peak Flow (13.7 mi2)			
Parameter	**Value**	**Regression Equation Valid Range**	
		Min	**Max**
Drainage Area (square miles)	111	0.5	2930
6 Hour 100 Year Precipitation (inches)	2.98	2.4	5.1

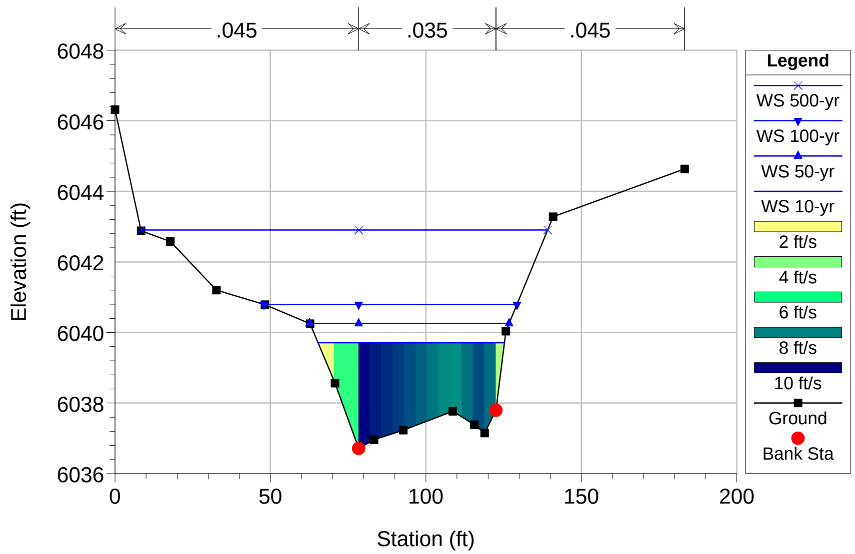
Table E.3.
USGS StreamStats Peak-Flows Streamflow Statistics Area-Averaged

Peak-Flows Streamflow Statistics Area-Averaged			
Statistic	**Flow (ft^3/s)**	**Prediction Error (percent)**	**Equivalent years of record**
PK2	545	65	
PK5	812	56	
PK10	1020	53	
PK25	1250	52	
PK50	1540	51	
PK100	1820	49	
PK200	2320	51	
PK500	2500	46	

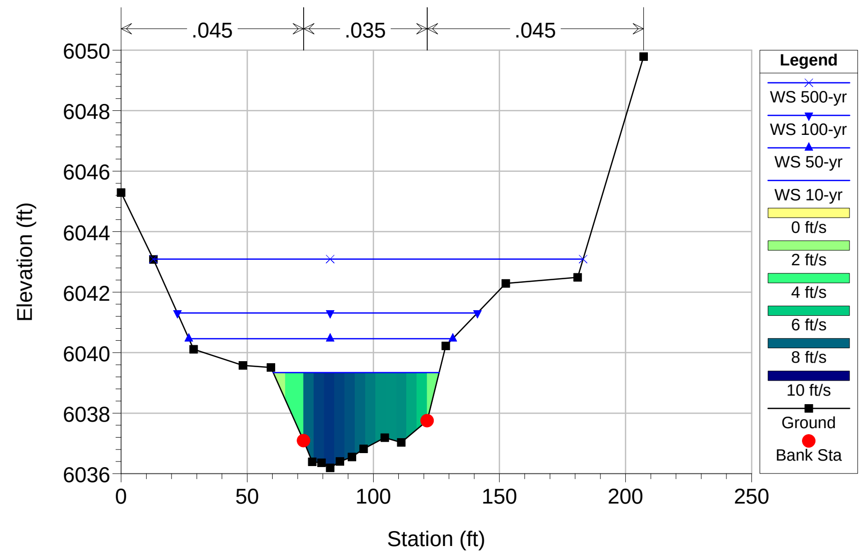
Appendix F – Hydraulic Model


E-15-AH HEC from Survey Plan: E-15-AH Plan 01 3/13/2013
South Boulder Cr E-15-AH
Legend
WS 500-yr
WS 100-yr
WS 50-yr
WS 10-yr
Ground
Elevation (ft)
6050
6045
6040
6035
6030
6025
0
50
100
150
200
250
300
350
Main Channel Distance (ft)

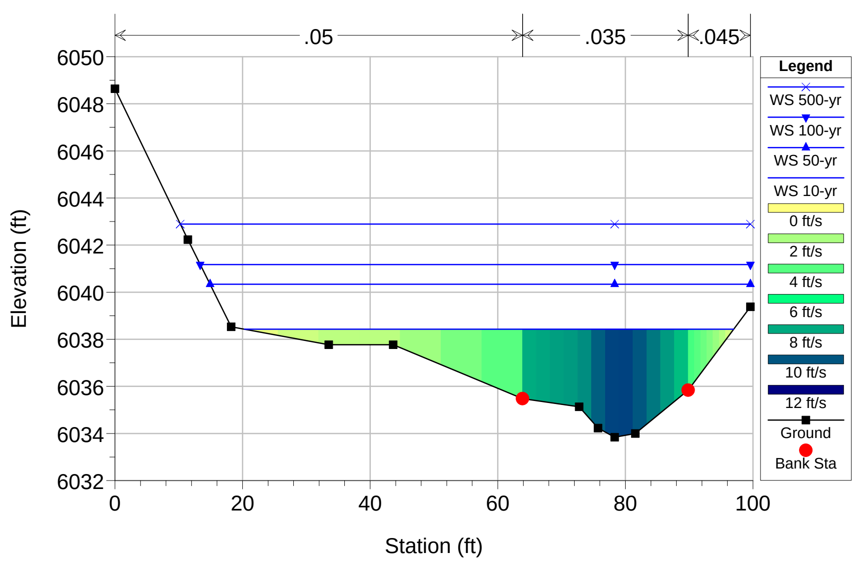
E-15-AH HEC from Survey Plan: E-15-AH Plan 01 3/13/2013



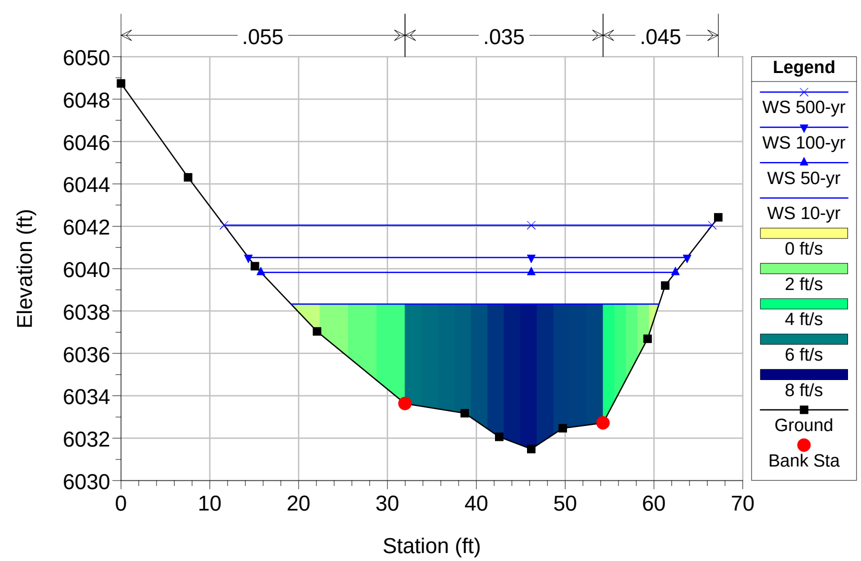
E-15-AH HEC from Survey Plan: E-15-AH Plan 01 3/13/2013

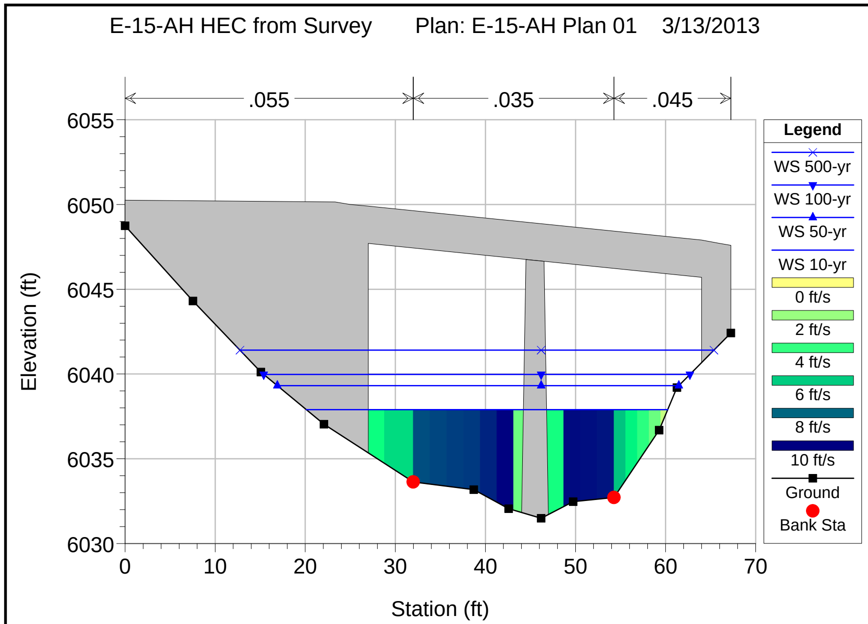


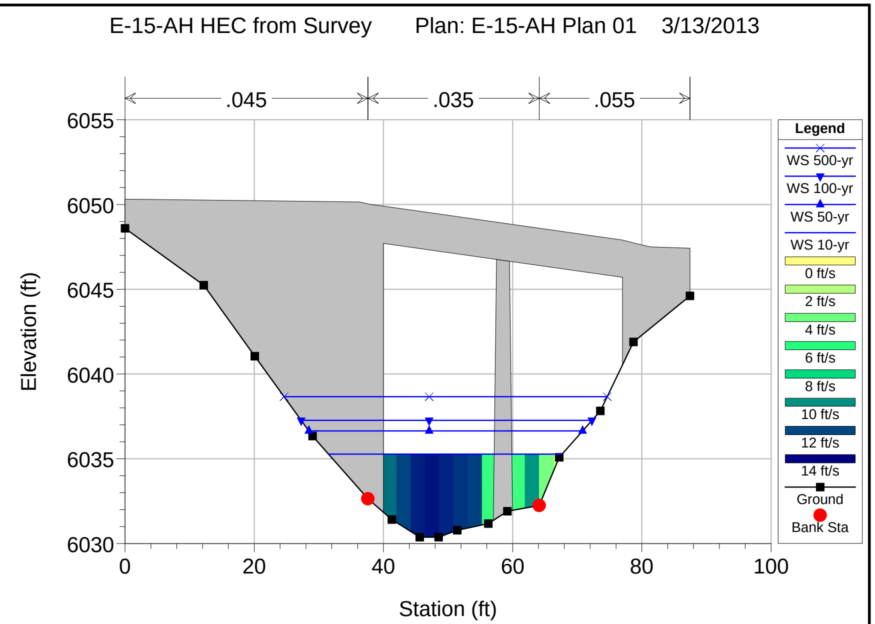
E-15-AH HEC from Survey Plan: E-15-AH Plan 01 3/13/2013

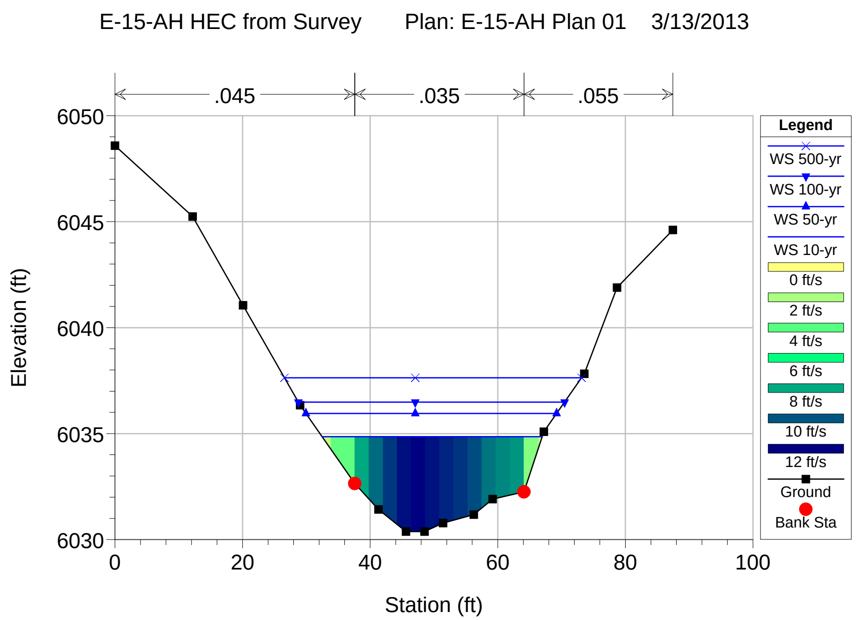


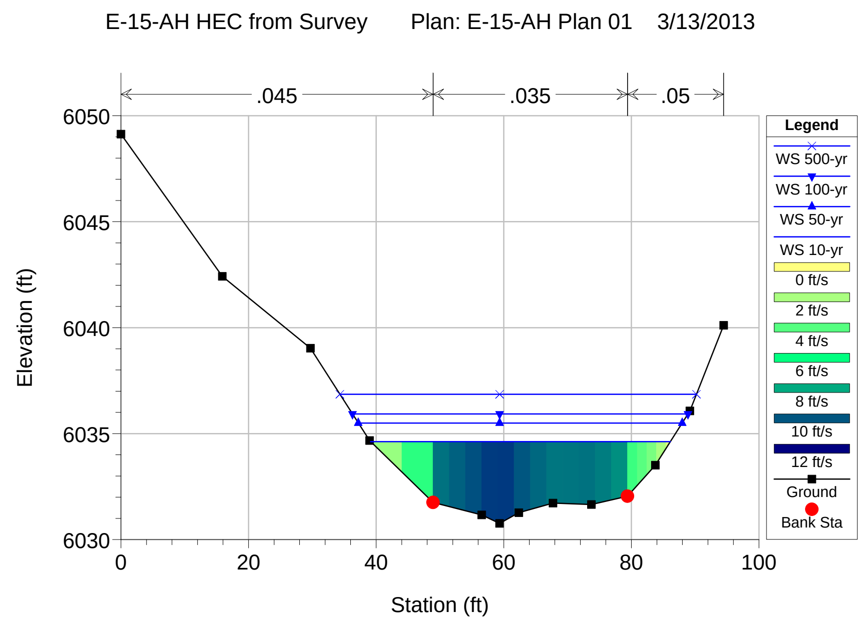
E-15-AH HEC from Survey Plan: E-15-AH Plan 01 3/13/2013



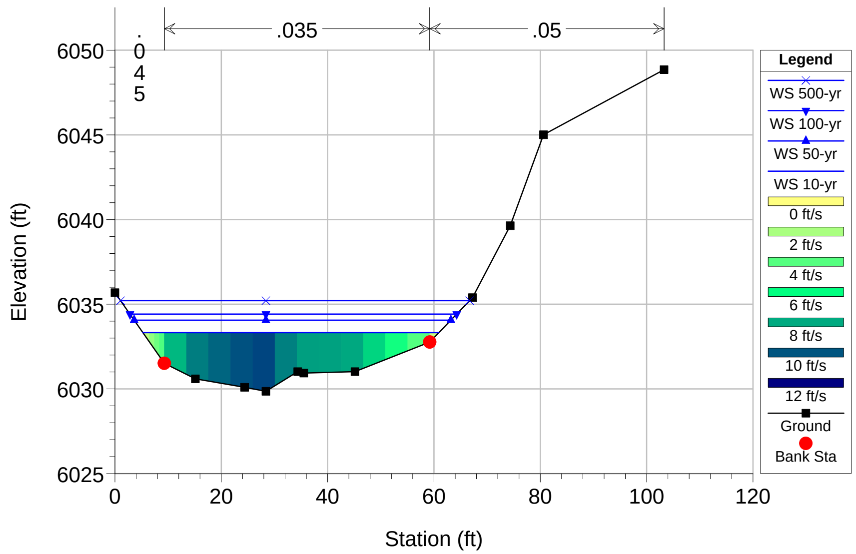

E-15-AH HEC from Survey Plan: E-15-AH Plan 01 3/13/2013
.055
.035
.045
Legend
WS 500-yr
WS 100-yr
WS 50-yr
WS 10-yr
0 ft/s
2 ft/s
4 ft/s
6 ft/s
8 ft/s
10 ft/s
Ground
Bank Sta
Elevation (ft)
Station (ft)


E-15-AH HEC from Survey Plan: E-15-AH Plan 01 3/13/2013
.045
.035
.055
Legend
WS 500-yr
WS 100-yr
WS 50-yr
WS 10-yr
0 ft/s
2 ft/s
4 ft/s
6 ft/s
8 ft/s
10 ft/s
12 ft/s
14 ft/s
Ground
Bank Sta
Elevation (ft)
Station (ft)


E-15-AH HEC from Survey Plan: E-15-AH Plan 01 3/13/2013
.045
.035
.055
Legend
WS 500-yr
WS 100-yr
WS 50-yr
WS 10-yr
0 ft/s
2 ft/s
4 ft/s
6 ft/s
8 ft/s
10 ft/s
12 ft/s
Ground
Bank Sta
Elevation (ft)
Station (ft)


E-15-AH HEC from Survey Plan: E-15-AH Plan 01 3/13/2013
.045
.035
.05
Legend
WS 500-yr
WS 100-yr
WS 50-yr
WS 10-yr
0 ft/s
2 ft/s
4 ft/s
6 ft/s
8 ft/s
10 ft/s
12 ft/s
Ground
Bank Sta
Elevation (ft)
Station (ft)

E-15-AH HEC from Survey   Plan: E-15-AH Plan 01   3/13/2013



HEC-RAS Plan: Plan 01   River: South Boulder Cr   Reach: E-15-AH

Reach	River Sta	Profile	Q Total	Min Ch El	W.S. Elev	Crit W.S.	E.G. Elev	E.G. Slope	Vel Chnl	Flow Area	Top Width	Froude # Chl
			(cfs)	(ft)	(ft)	(ft)	(ft)	(ft/ft)	(ft/s)	(sq ft)	(ft)	
E-15-AH	319	10-yr	1020.00	6036.71	6039.71	6039.71	6040.82	0.013435	8.76	126.65	59.99	1.00
E-15-AH	319	50-yr	1540.00	6036.71	6040.25	6040.25	6041.87	0.015041	10.63	160.24	64.18	1.10
E-15-AH	319	100-yr	1820.00	6036.71	6040.79	6040.79	6042.39	0.012013	10.64	199.55	81.37	1.01
E-15-AH	319	500-yr	2500.00	6036.71	6042.90		6043.68	0.003461	7.84	427.36	130.84	0.59
E-15-AH	293	10-yr	1020.00	6036.19	6039.34	6039.18	6040.26	0.010161	7.86	139.61	65.78	0.88
E-15-AH	293	50-yr	1540.00	6036.19	6040.46	6040.03	6041.30	0.006007	7.74	239.02	104.65	0.72
E-15-AH	293	100-yr	1820.00	6036.19	6041.31		6041.94	0.003560	6.86	333.95	118.97	0.57
E-15-AH	293	500-yr	2500.00	6036.19	6043.09		6043.50	0.001650	5.84	589.88	170.43	0.41
E-15-AH	214	10-yr	1020.00	6033.84	6038.43	6038.43	6039.52	0.008392	9.07	150.55	76.66	0.84
E-15-AH	214	50-yr	1540.00	6033.84	6040.34		6040.91	0.002921	7.10	307.75	84.70	0.53
E-15-AH	214	100-yr	1820.00	6033.84	6041.18		6041.69	0.002241	6.84	379.36	86.24	0.48
E-15-AH	214	500-yr	2500.00	6033.84	6042.90		6043.37	0.001591	6.76	530.29	89.36	0.42
E-15-AH	141	10-yr	1020.00	6031.49	6038.33	6036.51	6039.00	0.002683	6.96	178.17	41.43	0.51
E-15-AH	141	50-yr	1540.00	6031.49	6039.82	6037.65	6040.68	0.002612	8.01	243.63	46.67	0.53
E-15-AH	141	100-yr	1820.00	6031.49	6040.53	6038.18	6041.47	0.002578	8.47	277.50	49.39	0.53
E-15-AH	141	500-yr	2500.00	6031.49	6042.05	6039.27	6043.17	0.002499	9.38	356.87	54.95	0.54
E-15-AH	122		Bridge									
E-15-AH	80	10-yr	1020.00	6030.38	6034.85	6034.85	6036.49	0.011228	10.41	104.41	34.49	0.97
E-15-AH	80	50-yr	1540.00	6030.38	6035.95	6035.95	6038.00	0.010021	11.76	144.80	39.30	0.96
E-15-AH	80	100-yr	1820.00	6030.38	6036.49	6036.49	6038.71	0.009496	12.30	166.54	41.73	0.95
E-15-AH	80	500-yr	2500.00	6030.38	6037.63	6037.63	6040.22	0.008706	13.45	217.09	46.57	0.94
E-15-AH	70	10-yr	1020.00	6030.76	6034.62	6034.62	6035.96	0.011390	9.67	118.90	47.00	0.96
E-15-AH	70	50-yr	1540.00	6030.76	6035.50	6035.50	6037.19	0.010654	11.02	161.64	50.76	0.97
E-15-AH	70	100-yr	1820.00	6030.76	6035.93	6035.93	6037.78	0.010286	11.59	183.77	52.57	0.97
E-15-AH	70	500-yr	2500.00	6030.76	6036.86	6036.86	6039.05	0.009641	12.74	234.42	55.89	0.97
E-15-AH	0	10-yr	1020.00	6029.86	6033.33	6033.33	6034.47	0.013347	8.61	121.06	55.68	0.99
E-15-AH	0	50-yr	1540.00	6029.86	6034.06	6034.06	6035.52	0.011991	9.80	163.46	59.57	0.98
E-15-AH	0	100-yr	1820.00	6029.86	6034.42	6034.42	6036.03	0.011513	10.32	184.91	61.45	0.98
E-15-AH	0	500-yr	2500.00	6029.86	6035.21	6035.21	6037.14	0.010530	11.35	235.59	65.67	0.97

Appendix G – Scour Calculations

PROJECT: E-15-AH
DATE: 20-Mar-13
EVENT: 500-Year

PIER SCOUR
CSU Equation For both Live bed and Clear water scour

$$\frac{y_s}{y_1} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{y_1}\right)^{0.65} Fr_1^{\,0.43}$$

Variable		Description	Source
y1=	9.7	Flow depth directly upstream of pier in ft	HEC-RAS
K1=	0.9	Correction factor for pier nose shape Table 6-1 (sharp nose)	Shape determined from site visit
K2=	1	Correction factor for angle of attack of flow from Table 6-2	0 degrees
K3=	1.1	Correction factor for bed condition from Table 6-3	Assumed no dunes
a=	3.00	Pier width, (ft)	Site visit
Fr1=	0.48	Froude number directly upstream of the pier (calculated)	
V1=	8.5	Mean Velocity of flow directly upstream of pier (ft/s)	HEC-RAS
D50=	152.4	Particle Size in mm	Field Determination
D95=	609.6	Particle Size in mm	Field Determination
K4	1.0	If D50<2 mm or D95<20 mm, then K4 = 1	
		If D50>2 mm or D95>20 mm, then K4 = 0.4(Vr)^0.15	
		Basically K4 is between 0.4 (min value) and 1, 1 probably is the most conservative.	
Ys=	**6.5**	**Scour depth (ft)**	

PROJECT: E-15-AH
DATE: 20-Mar-13
EVENT: 500-Year

CONTRACTION SCOUR

Live Bed Transport of bed material in the upstream reach into the bridge cross section (HIGH VELOCITIES AND SMALL BED MATERIAL WILL CREATE LIVE BED SCOUR)

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

VARIABLE		Description	Source
A1=	210.29	Flow area of the stream main channel (ft2)	Main channel flow area XS 4 (RAS)
A2=	170.13	Flow area of the contracted section (ft2)	Bridge opening area (RAS)
y1=	9.43	Average depth in the stream main channel, (ft)	A1/W1
yo=	8.53	Average depth in the contracted section, (ft)	A2/W2
Q1=	1971.63	Flow in the upstream channel transporting sediment, (cfs)	Main channel flow XS 4 (RAS)
Q2=	1859.95	Flow in the contracted channel, (cfs)	Flow in channel at bridge (RAS)
W1=	22.29	Bottom/top width of the upstream main channel, (ft)	Bank stationwidth XS 4 (RAS)
W2=	19.94	Bottom/top width of the main channel in the contracted section, (ft)	Bridge US section bottom deck width
S1=	0.009280	Slope of the energy grade line of the main channel (ft/ft)	Average E.G. slope upstream of bridge
omega (w)=	3.146325	Find D50 then see figure (right) - Fall velocity (ft/s)	Estimate from Site visit
V*=	1.68	Shear Velocity (ft/s)	
V*/omega(w)=	0.53		
k1=	0.64		See Table 1
y2=	9.63	Average Depth in the contracted section (scoured) (ft)	
Contraction Scour=	1.10	**Average Contraction Scour Depth (ft)**	

Vavg < Vc, Use Clear Water Scour Equation

Clear-Water

VARIABLES

yo=	8.53	Average depth in the contracted section,
Q=	1859.95	Discharge through the bridge or on the setback overbank area at the bridge associated with the width W
W=	19.94	Bottom or top width of the contracted section
D50=	0.5	Median diameter (ft) - Sieve Analysis
Dm	0.6250	Diameter of the smallest non-transferable particle in the bed material (1.25 D50) in the contracted section (ft)
Ku=	0.0077	Constant (English Units)
y2=	6.93	Avg equilibrium depth in the contracted section after contraction scour (ft)
Contraction Scour=	-1.60	**Average Contraction Scour Depth (ft)**

PROJECT: E-15-AH
DATE: 13-May-13
EVENT: 500-Year

ABUTMENT SCOUR (Left)
Froehlich's Abutment Scour Equation

$$\frac{y_s}{y_a} = 2.27 K_1 K_2 \left(\frac{L'}{y_a}\right)^{0.43} Fr^{0.61} + 1$$

Variable		Description	Source
Sta	141	Ras Station for Computing Encroachment	RAS XS 141
S1=	0	RAS Station of Left Encroachment Begin	RAS LOB Output
S2=	28.78	Water Surface Left (or Left Encroachment End if split flow)	RAS LOB Output
K1=	0.82	Abutment shape coefficient from Table 7.1	CDOT Plans
θ=	90	Angle of Orientation of Abutment to Flow (See Figure 7.5 in HEC 18)	Site Visit
K2=	1.00	(θ/90)^.13	
L`=	9.59	Length of active flow obstructed by the embankment (ft) See Fig 7.4 in HEC 18	RAS LOB Output
Ae=	53.96	Flow area of the approach cross section obstructed by embankment (ft^2)	RAS LOB Output
Fr=	0.46088	Froude number of approach flow upstream of abutment	
Qe=	193.23	Flow obstructed by the approach abutment and approach embankment (ft^3/s)	RAS LOB Output
y1=	8.6	Depth of flow at the abutment (ft)	RAS Model - depth at toe (US face)
v1=	3.51	Velocity upstream of the abutment (ft/s)	RAS Velocity Distribution (US face)
ya=	1.87	Average depth of flow in the floodplain (Ae/L) (ft)	
L=	28.78	Length of embankment projected normal to the flow (ft)	Survey/RAS Model
Ve=	3.58	Qe/Ae (ft/s)	
Abutment Scour (ys) =	**6.3**	**Scour Depth (ft)**	
L/Y1 =	**3.35**	**Use Froehlich Equation**	

ABUTMENT SCOUR (Right)
Froehlich's Abutment Scour Equation

Variable		Description	Source
Sta	141	Ras Station for Computing Encroachment	RAS XS 141
S1=	63.36	RAS Station of Right Encroachment Begin	RAS ROB Output
S2=	67.25	Water Surface Right (or Right Encroachment End if split flow)	RAS ROB Output
K1=	1	Abutment shape coefficient from Table 7.1	CDOT Plans
θ=	90	Angle of Orientation of Abutment to Flow (See Figure 7.5 in HEC 18)	Site Visit
K2=	1.00	(θ/90)^.13	
L`=	3.89	Length of active flow obstructed by the embankment (ft) See Fig 7.4 in HEC 18	RAS ROB Output
Ae=	2.75	Flow area of the approach cross section obstructed by embankment (ft^2)	RAS ROB Output
Fr=	0.27	Froude number of approach flow upstream of abutment	
Qe=	3.57	Flow obstructed by the approach abutment and approach embankment (ft^3/s)	RAS ROB Output
y1=	7.8	Depth of flow at the abutment (ft)	RAS Model - depth at toe (US face)
v1=	1.23	Velocity upstream of the abutment (ft/s)	RAS Velocity Distribution (US face)
ya=	0.71	Average depth of flow in the floodplain (Ae/L) (ft)	
L=	3.89	Length of embankment projected normal to the flow (ft)	
Ve=	1.30	Qe/Ae (ft/s)	
Abutment Scour (ys) =	**2.2**	**Scour Depth (ft)**	
L/Y1 =	**0.5**	**Use Froehlich Equation**	

PROJECT: E-15-AH
DATE: 16-Aug-13
EVENT: 500-year event

ABUTMENT SCOUR
NCHRP 24-20 Abutment Scour Approach

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

$y_s = y_{max} - y_0$

Live Bed Conditions:

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

Clear Water Conditions:

$$y_c = \left(\frac{q_{2f}}{K_u D_{50}^{1/3}}\right)^{6/7}$$

Variable		Description	Source
q_1=	88.45	Upstream unit discharge, ft^2/s (m^2/s)	HEC Output Q/W
q_{2c}=	67.57	Unit discharge in the constricted opening accounting for non-uniform flow distribution, ft^2/s (m^2/s)	HEC Output Q/W
q_{2c}/q_1=	0.76	Ratio of upstream unit discharge to unit discharge in the constricted opening	
Bed Conditions=	C	If Live bed conditions leave blank, if clear-water conditions use "C"	
α_A or α_B=	1.20	Amplification factor for live-bed (α_A) or clear-water (α_B) conditions. From Figs. 8.9 through 8.12	Figures 8.9 through 8.12 (HEC-18)
y_1=	9.43	Upstream flow depth, ft (m)	HEC Output
K_u=	11.17	11.17 English units, 6.19 SI units	HEC-18
D_{50}=	0.500	Particle size with 50 percent finer, ft (m)	Grain size distribution
y_c=	5.70	Flow depth including clear-water contraction scour, ft (m)	HEC Output
y_{max}=	6.84	Maximum flow depth resulting from abutment scour, ft (m)	HEC Output
y_0(left)=	6.10	Flow depth at left abutment prior to scour, ft (m)	HEC Output
y_0(right)=	6.90	Flow depth at right abutment prior to scour, ft (m)	HEC Output

y_s (left)=	0.74	Left abutment scour depth, ft (m)
y_s (right)=	0.00	Right abutment scour depth, ft (m)

Appendix H – Documentation for Monitoring or Countermeasures Recommendations

Appendix I – Bridge Stability Documentation