



NHEC 2014

National Hydraulic Engineering Conference
Designing Sustainable Infrastructure in a Changing Environment



Yellowstone River at Huntley, MT

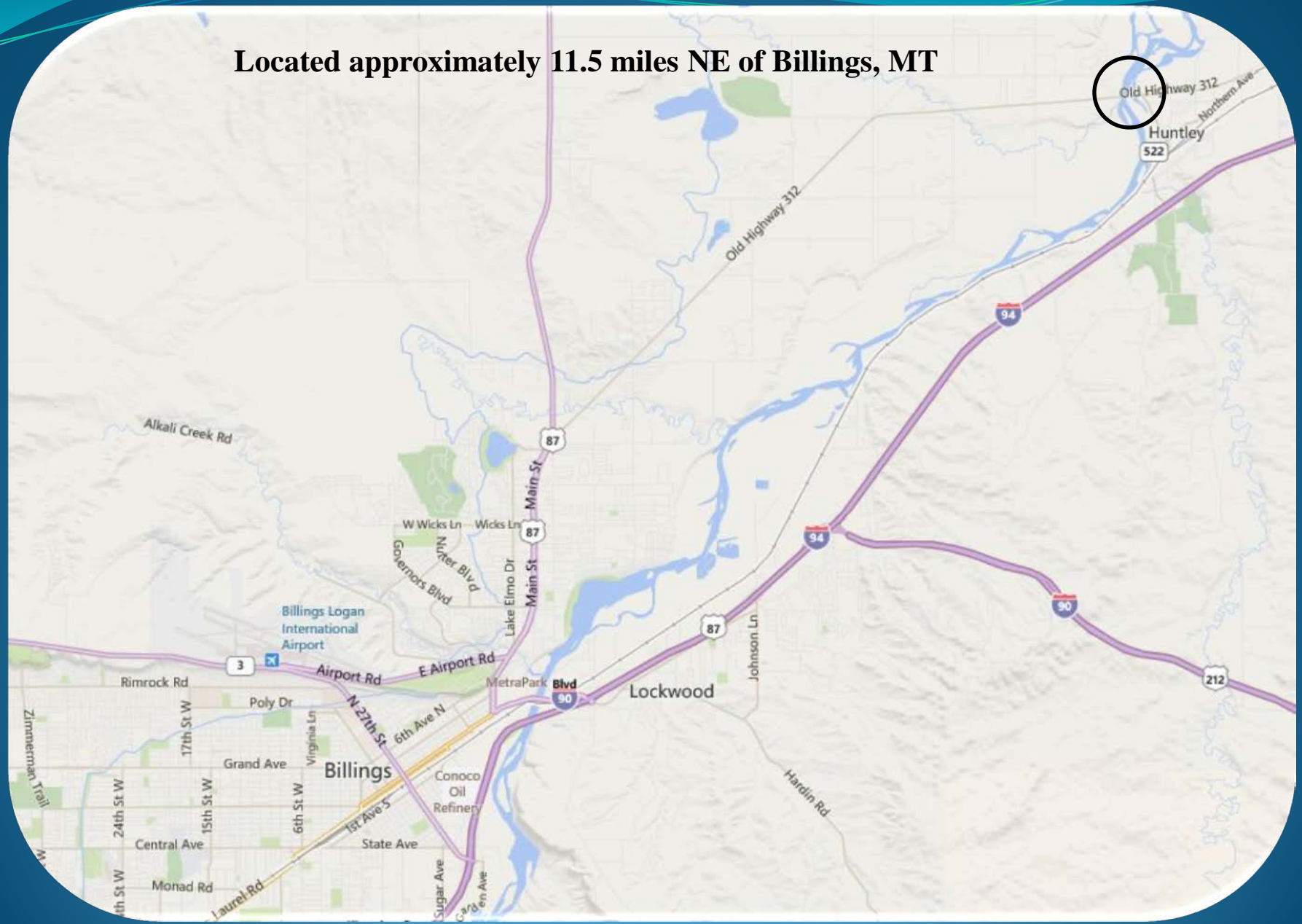
Bridge Scour Countermeasure Failure Investigation

Russell Brewer, P.E.



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

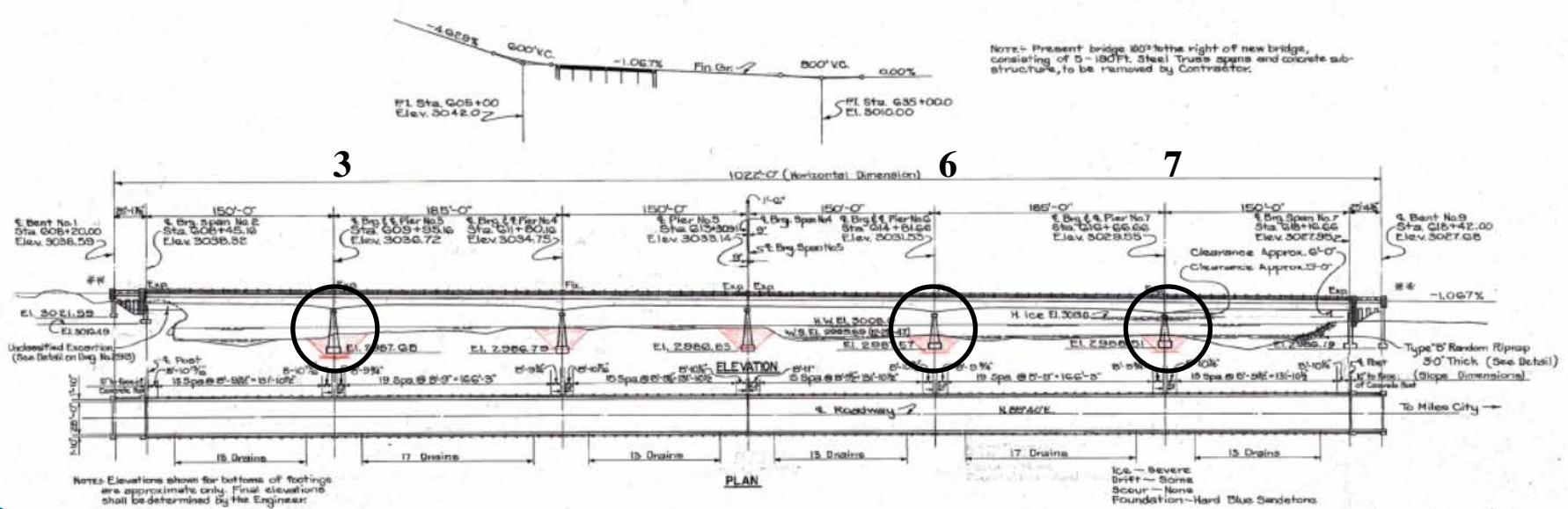
Located approximately 11.5 miles NE of Billings, MT



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

Initial Scour Analysis Completed April 10, 1998

FED. ROAD DIST. NO.	STATE	FED. AID PROJ. NO.	FISCAL YEAR
1	MONT.	27-0739	7



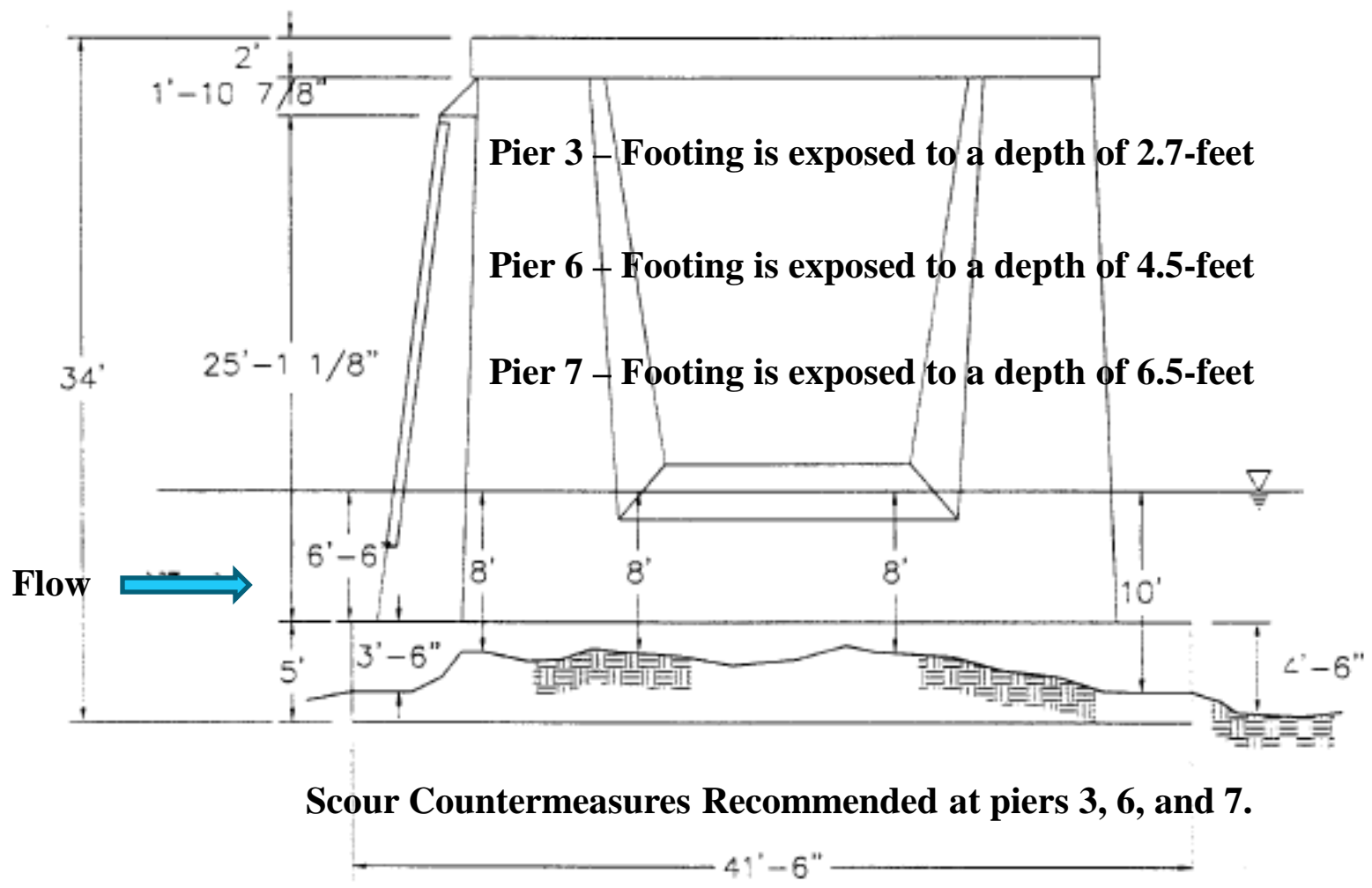
- Total pier scour estimated at 18.2-feet
- Estimated Scour plots below the bottom of the footing elevations at piers 3, 6, and 7
- Footings “keyed” about 2-feet into Hard Blue Sandstone
- Structure placed on District Emergency Watch List (NBIS Item 113 Code 3)



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

EAST ELEVATION

9-23-1998 UW Inspection



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

Scour mitigation project completed December 2006

MONTANA DEPARTMENT OF TRANSPORTATION

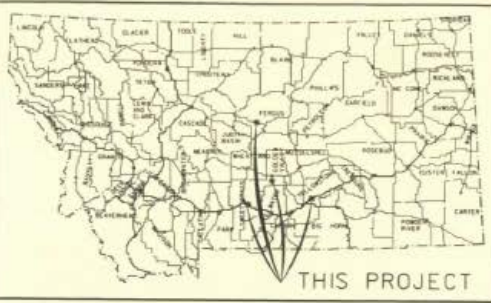
AS-BUILT DRAWINGS

FEDERAL AID PROJECT NO. BH 0002(745)

D5 - SCOUR PROTECTION

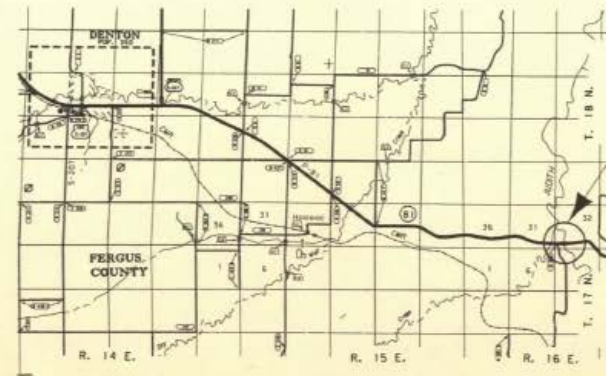
DESIGN DATA	
ADT -	N/A
ADT -	N/A
DAV -	N/A
T -	N/A
V -	N/A
MIN ISALS -	N/A
GROWTH RATE -	N/A

LETTING DATE - Dec 1, 2005
 Completion Date - Dec 11, 2006



SITE 1 - L56788
 Yellowstone River

YELLOWSTONE, SWEETGRASS, FERGUS & GOLDEN VALLEY COUNTIES



SITE 3 - P81
 Judith River



SITE 2 - L49125
 Upper Deer Creek



SITE 4 - S300
 Musselshell River

MONTANA DEPARTMENT OF TRANSPORTATION	
APPROVED: <i>September 27, 2005</i> JIM LYNCH DIRECTOR OF TRANSPORTATION	
BRIDGE ENGINEER	
U.S. DEPARTMENT OF TRANSPORTATION FEDERAL HIGHWAY ADMINISTRATION	
APPROVED:	DATE:
DESIGN ADMINISTRATOR	DATE

MONTANA DEPARTMENT OF TRANSPORTATION
 MONTANA
 CAD

FILE NAME: D:\PFT\LO1_1.DWG

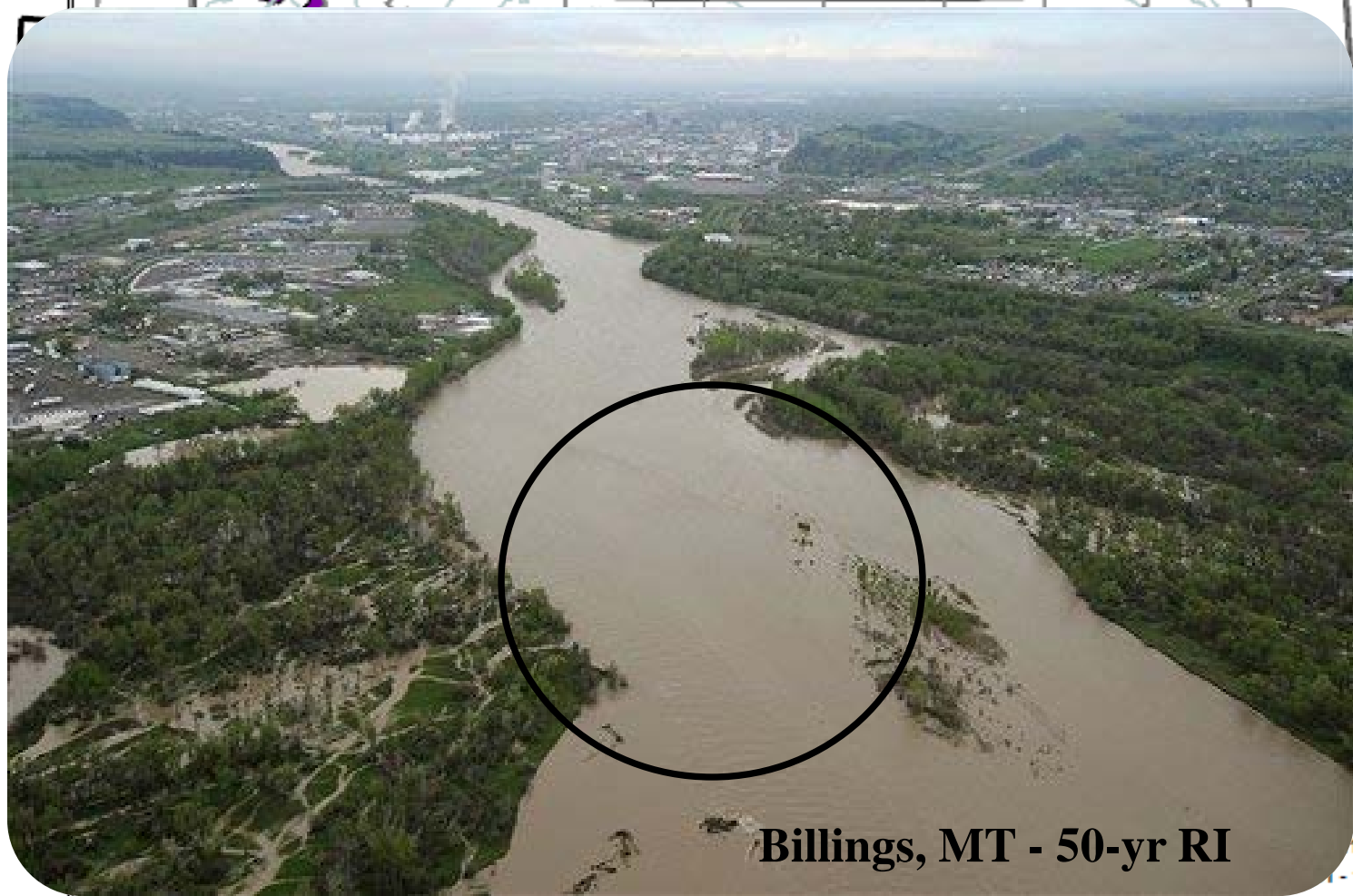
ASSOCIATED PROJECT AGREEMENT NUMBERS
 R/W & I.C. BH 0002(1784)
 P.S. BH 0002(1518)

X81014



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

Mountain Snow Water Equivalent

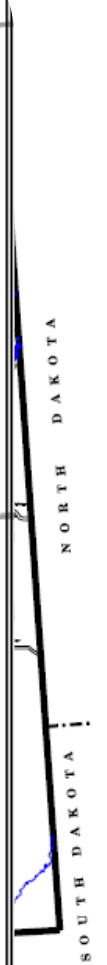


Billings, MT - 50-yr RI

2011

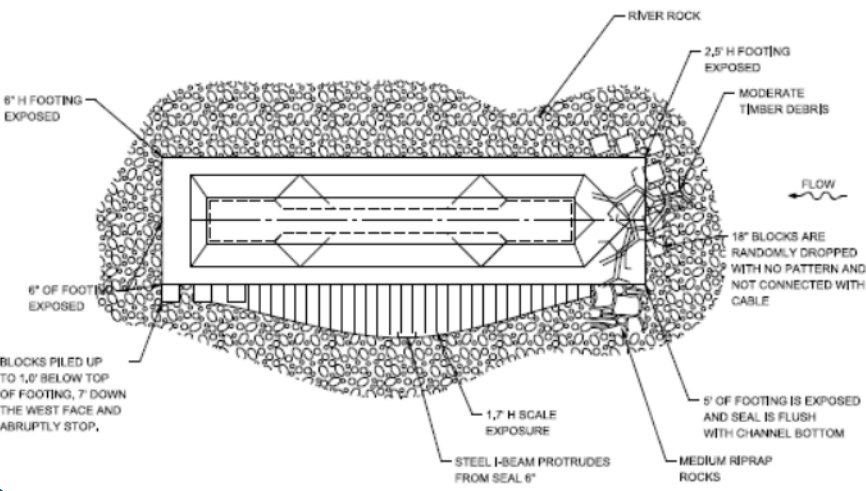
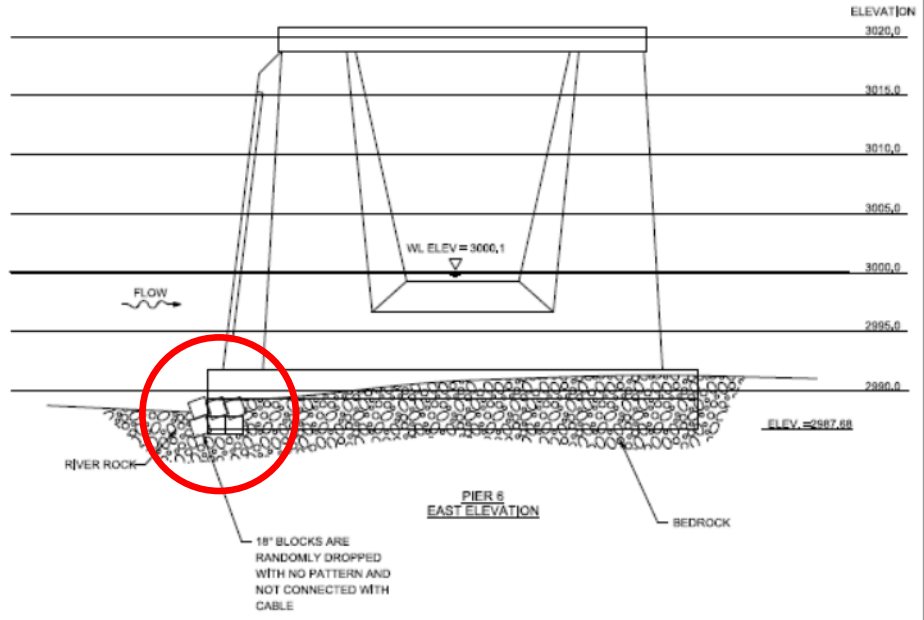
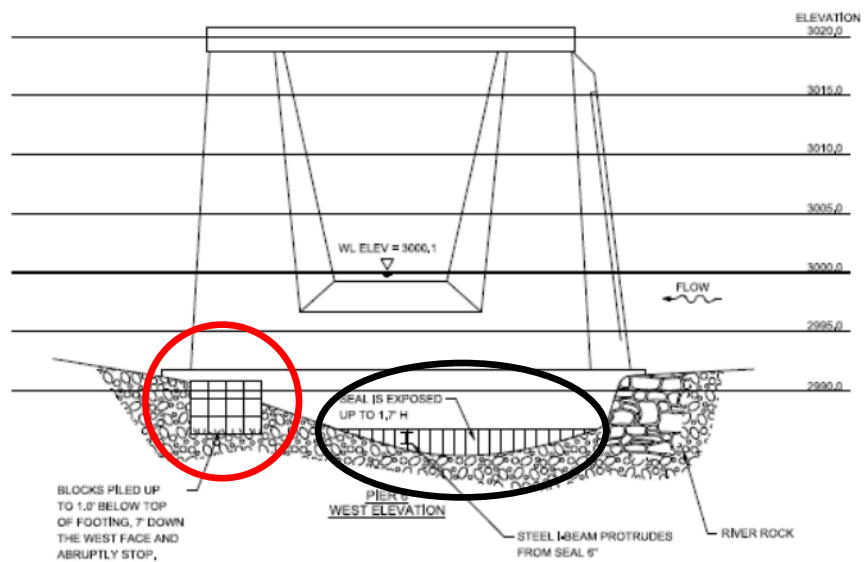
Sub-Basin
 Average (Over 150)
 (131 - 150)
 (111 - 130)
 (91 - 110)

- Below Average (71 - 90)
- Much Below Average (51 - 70)
- Extremely Below Average (Below 51)



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

Underwater Inspection Report September-2011



Indicates Counter Measures at pier 6 failed
Scour extends below bottom of footing elevation

GRAPHIC SCALE MEASURED IN FEET 	DATE SEPT 2011	2121 Old Hickory Tree Road St. Cloud, Florida 34772 PH: 407.975.1880 FAX: 407.975.0144	ROUTE 56788 OVER YELLOWSTONE RIVER BRIDGE NO. L56788012+07001	PAGE 4
	INFRASTRUCTURE ENGINEERS, INC.			PIER 6

What Happened?

MDT Scour Team

- Implement POA due to CM Failure
- Review Available Data
- Request Additional Data
- Determine what led to CM Failure
 - Design Features
 - Construction Techniques
 - Hydraulic Forces
 - Other Factors



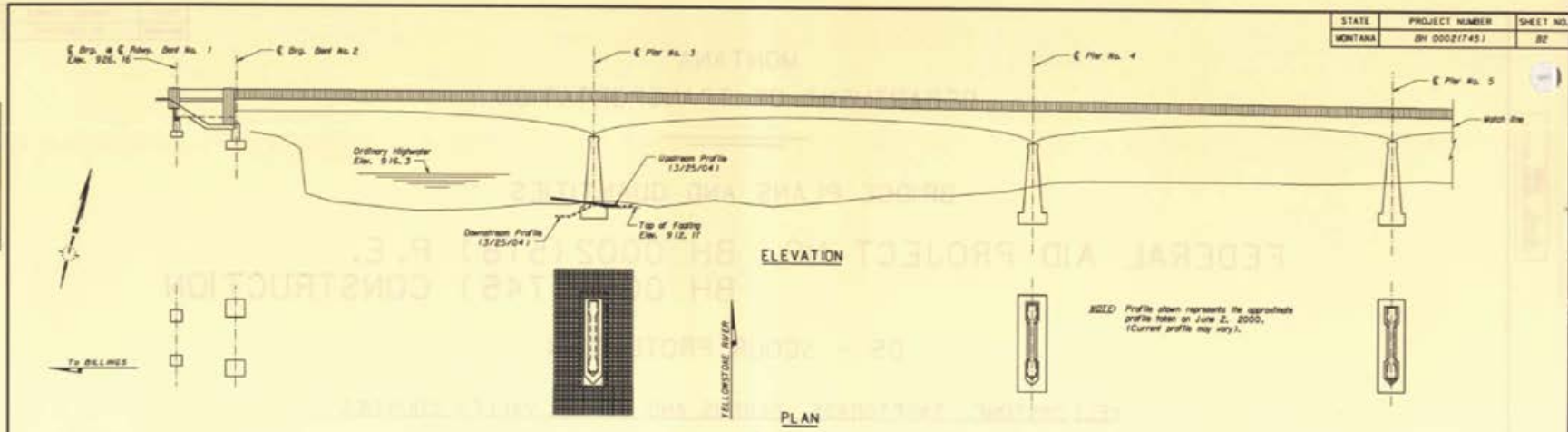
Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

Determine Mechanisms of failure:

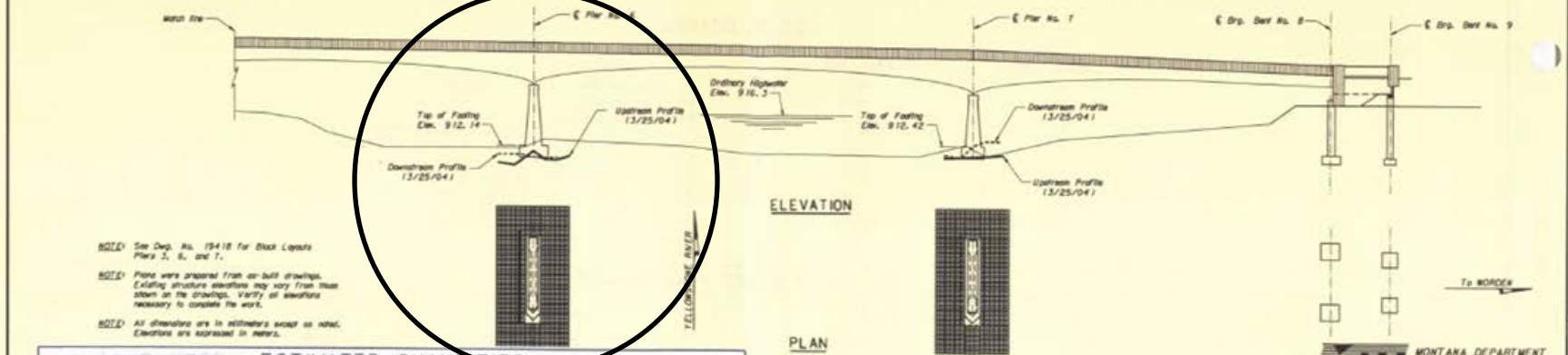
- Design Features
 - Review Plans



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT




STATE	PROJECT NUMBER	SHEET NO.
MONTANA	BH 000217451	82



- NOTE: See Dep. No. 19418 for Block Layouts Piers 3, 6, and 7.
- NOTE: Plans were prepared from as-built drawings. Existing structure elevations may vary from those shown on the drawings. Verify all elevations necessary to complete the work.
- NOTE: All dimensions are in millimeters except as noted. Elevations are expressed in meters.

ESTIMATED QUANTITIES				
PIER	BLOCK MATTRESS (m ²)	ROCK FILL (m ³)	GEOTEX EROSION-CLASS 2 AND 3 RIPRAP (m ³)	REMOVE STRUCTURE (L SUM)
3	158.2	0	158.2	
6	156.8	357	156.8	
7	155.7	62.8	155.7	
TOTAL	470.7	419.8	470.7	1,0623

 MONTANA DEPARTMENT OF TRANSPORTATION
 BRIDGE OVER YELLOWSTONE RIVER
 NEAR HUNTLEY
 FEDERAL AID PROJECT NO. BH 000217451
 YELLOWSTONE COUNTY
 SCOUR MITIGATION - SITE

DESIGNED	P-3-03	R.J.B.
DRAWN	JC-18-03	D.W.C.
CHECKED	P-R-05	J.S.O.
REVISED		
REVISED		

Scale = 11/250

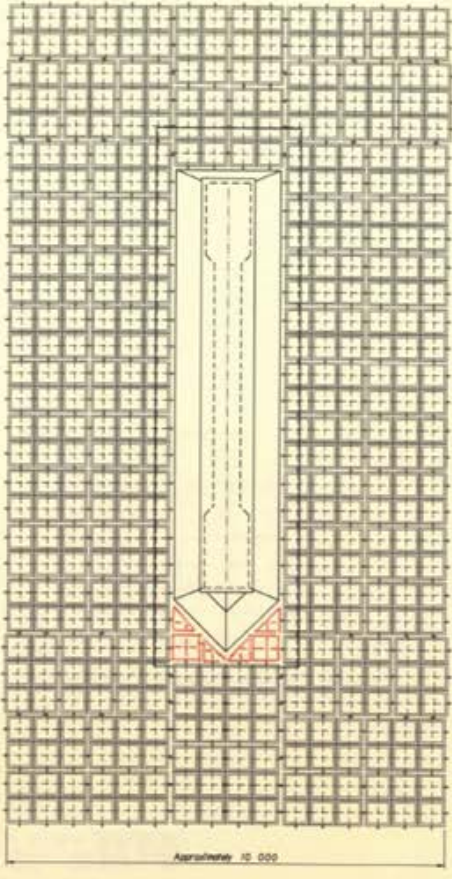
FILENAME: 46788Perry1.dgn DRAWING NO. 19417

46788Perry1.dgn
 10/14/2005
 9:20:26 AM CFS - 00287

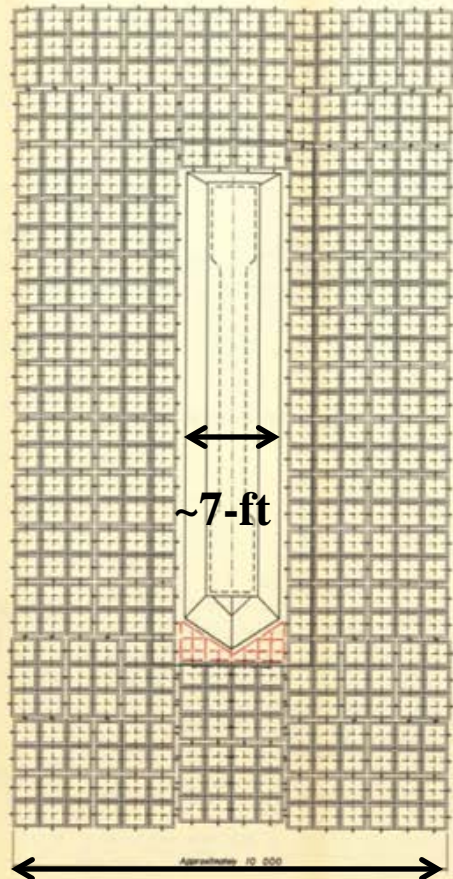
Old US Highway 312 Crossing the Yellowstone River at Huntley, MT



STATE	PROJECT NUMBER	SHEET NO.
MONTANA	BH 0002(745)	03

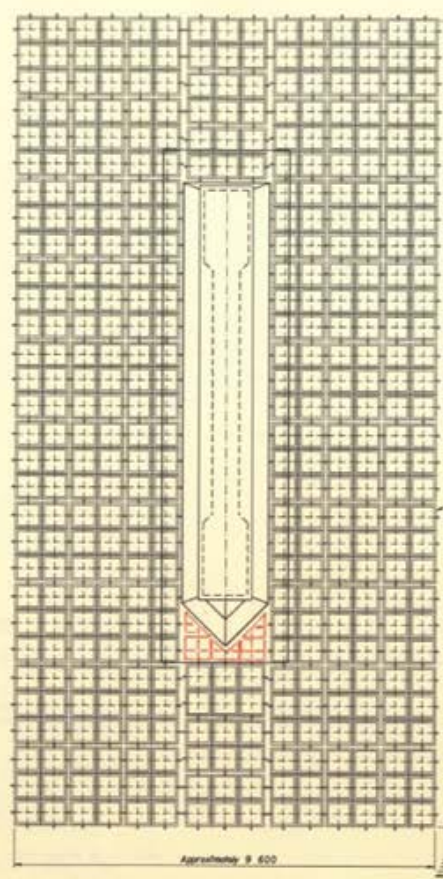


EXAMPLE BLOCK LAYOUT (PIER NO. 3)



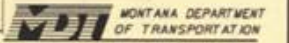
EXAMPLE BLOCK LAYOUT (PIER NO. 6)

~35-ft



EXAMPLE BLOCK LAYOUT (PIER NO. 7)

~68-ft



BRIDGE OVER YELLOWSTONE RIVER
NEAR HUNTLEY
FEDERAL AID PROJECT NO. BH 0002(745)
YELLOWSTONE COUNTY
MATTRESS LAYOUT

Scale - 1 : 50

DESIGNED	8-2-03	R.J.B.
DRAWN	12-19-03	D.W.C.
CHECKED	8-29-03	J.S.O.
REVISIONS		
REVISIONS		
REVISIONS		

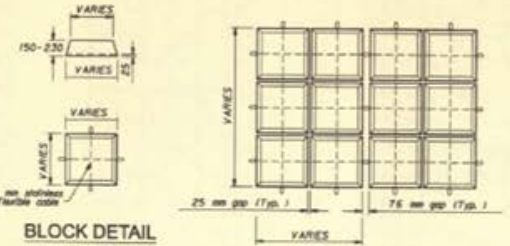
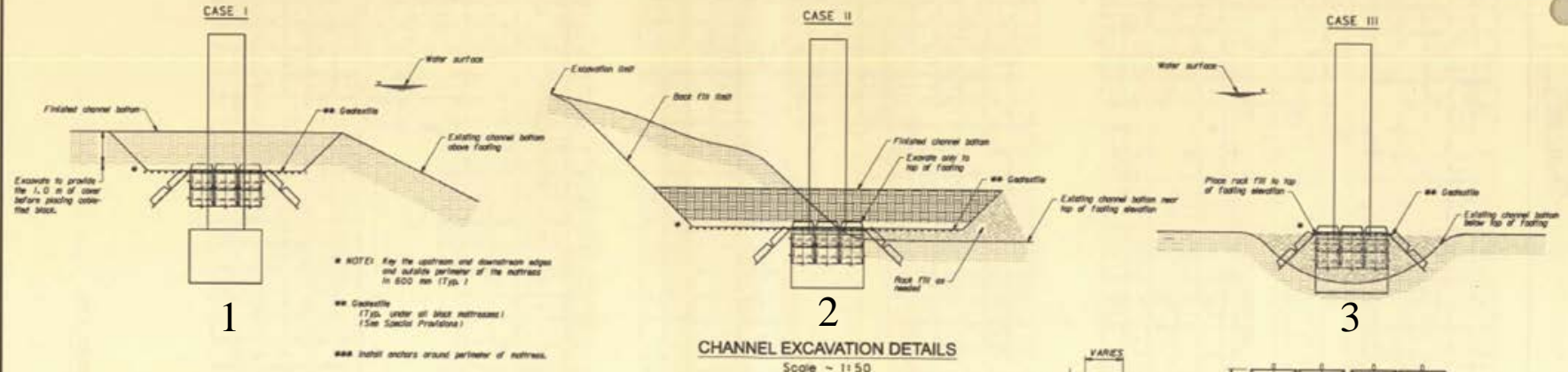
FILENAME: 457887arry2.dgn DRAWING NO. 19418

NOTE: Mattress cables that block mattresses to fit pier as shown.

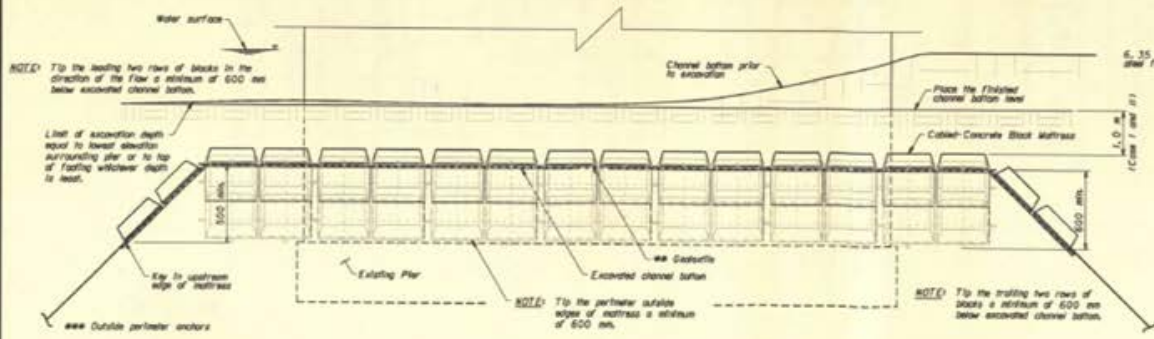
01/19/04
 11:20:13 AM
 CYS - 10277

Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

STATE	PROJECT NUMBER	SHEET NO.
MONTANA	BH 0002(1745)	BH



CABLED - CONCRETE BLOCK MATTRESS LAYOUT
Scale ~ 1:20



BRIDGE OVER YELLOWSTONE RIVER
NEAR HUNTLEY

FEDERAL AID PROJECT NO. BH 0002(1745)

YELLOWSTONE COUNTY

MISCELLANEOUS DETAILS

DESIGNED	R-3-07	R.C.J.B.
DRAWN	12-19-03	D.W.C.
CHECKED	8-22-09	J.S.G.
REVISED		
REVISED		
REVISED		

11/1/04 48780.mxd(1).dgn
10/14/2005
8:25:48 AM CFS - 10077

Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

Determine Mechanisms of failure:

➤ Design Features

- Review Plans

➤ Construction

- Method of Construction
- Review Placement of ACB's



US Highway 312 Crossing the Yellowstone River at Huntley, MT



• Pier 6

Challenges

- Site access
- Water depth at low flow = 9-feet
- How to isolate the work area?

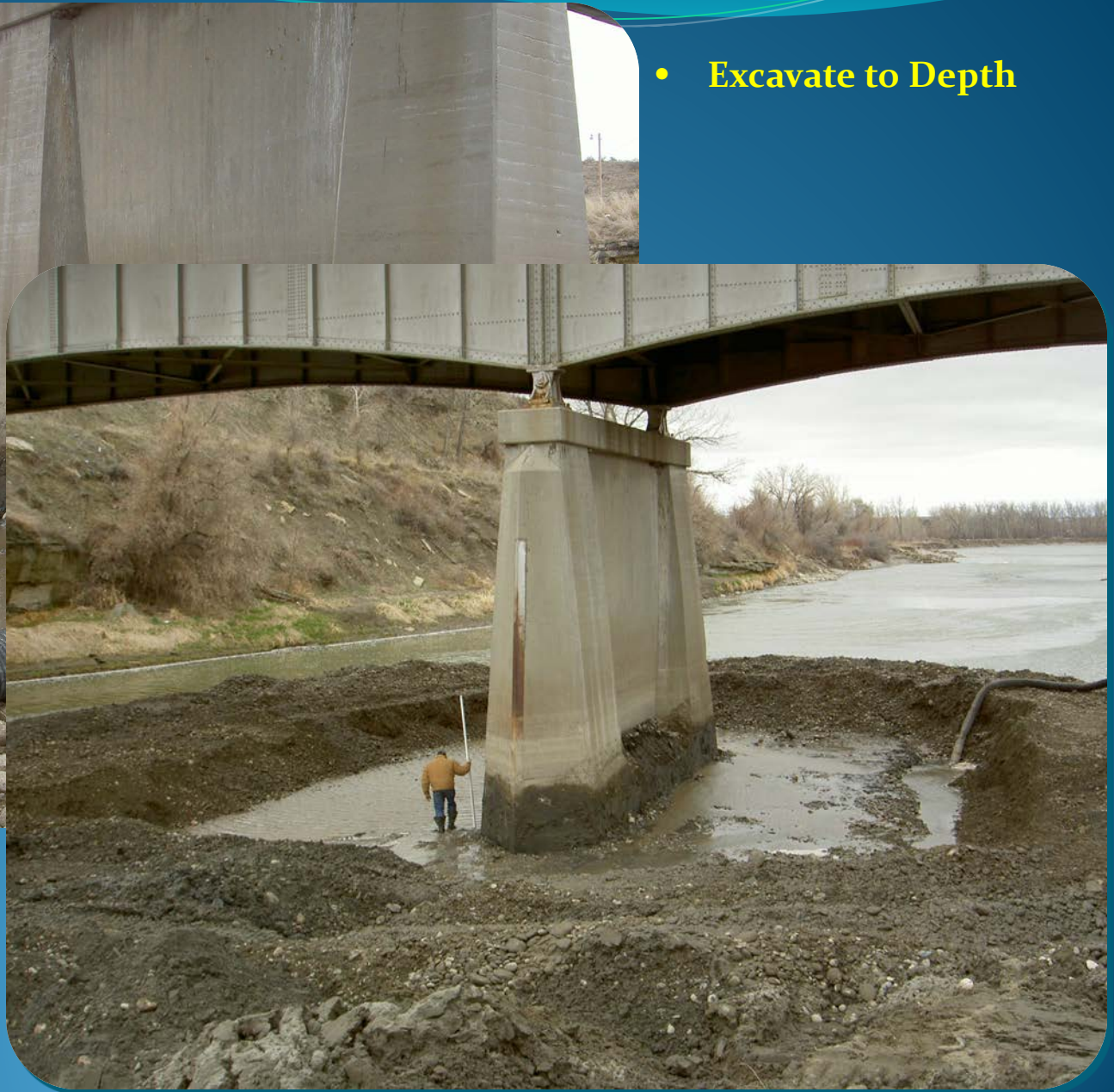
Contractors Solution

- Earthen Cofferdams



US Highway 312 Crossing the Yellowstone River at Huntley, MT

- Excavate to Depth



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

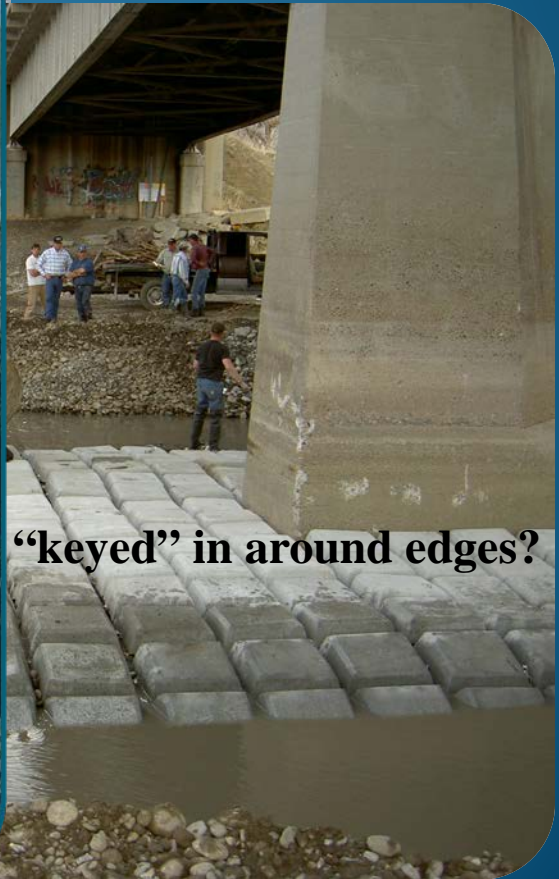


Block protrusion minimized?

- Place ACB Mattress



ACB Mattress anchored US and DS?



ACB Mattress "keyed" in around edges?

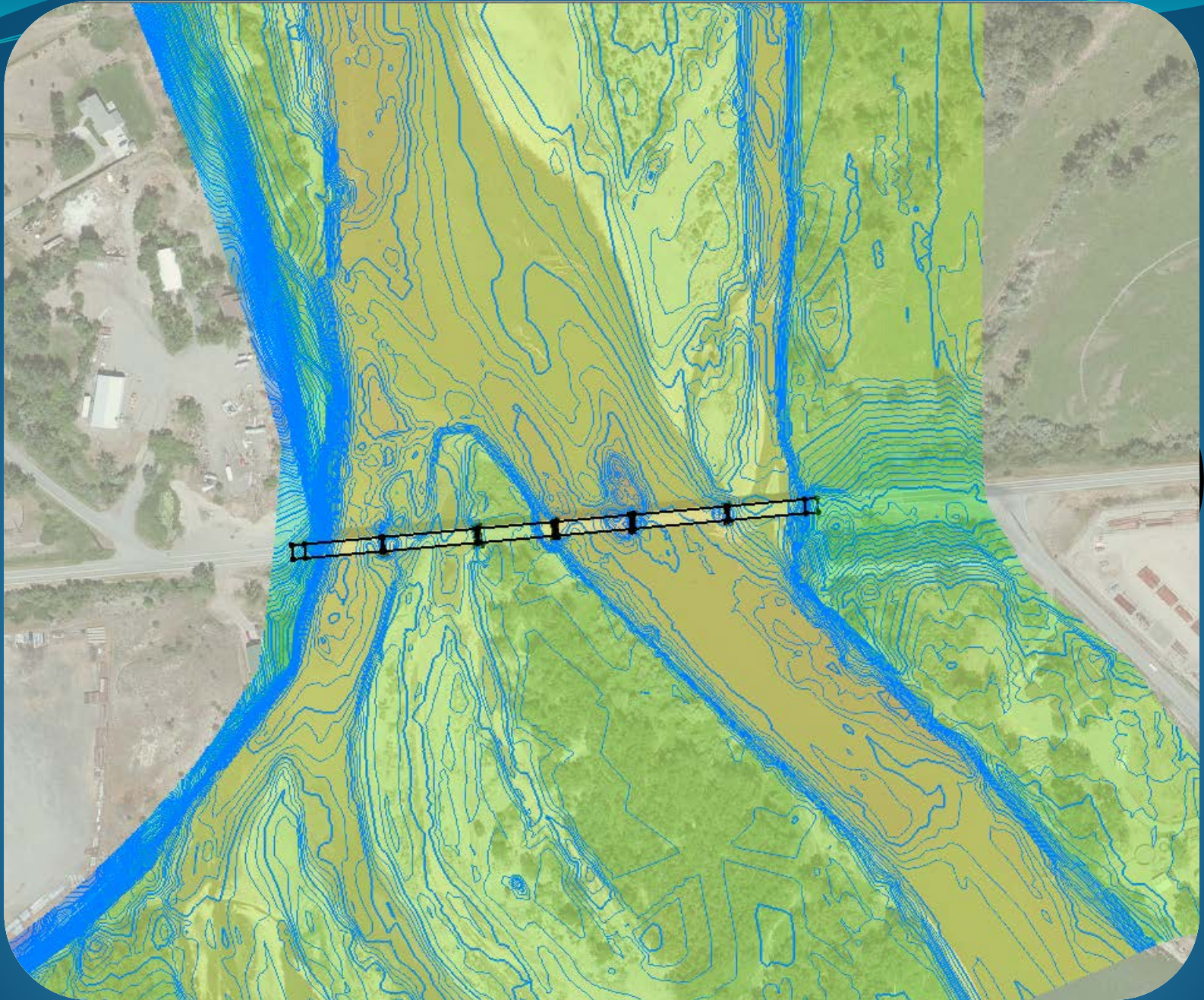
Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

Determine Mechanisms of failure:

- Design Features
 - Review Plans
- Construction Techniques
 - Review Methods of Construction
- Data Requested
 - Bathymetric Survey



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

Determine Mechanisms of failure:

- Design Features
 - Review Plans
- Construction Techniques
 - Review Methods of Construction
- Data Requested
 - Bathymetric Survey
- Hydraulic Forces
 - Flood Flow

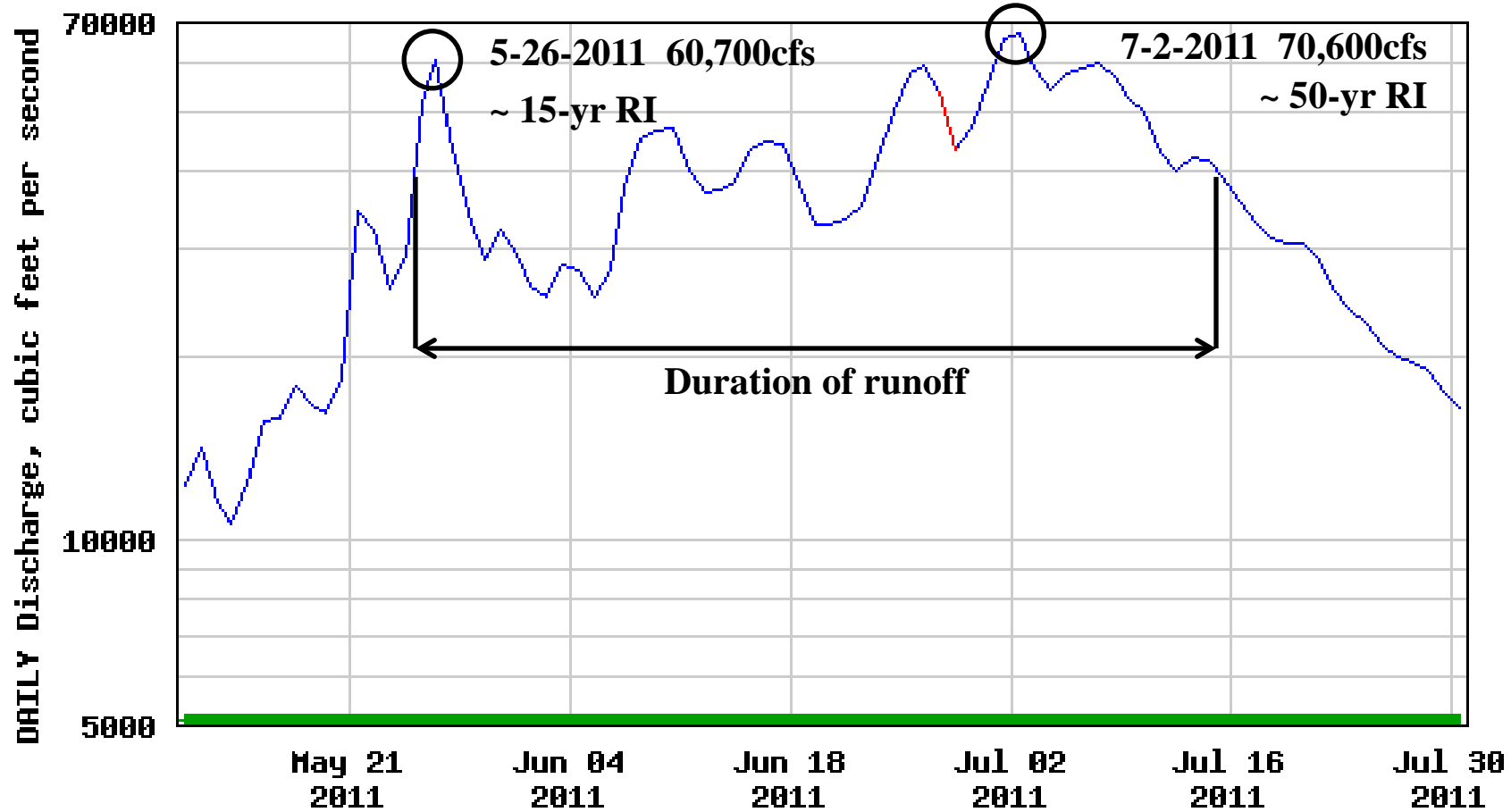




Old US Highway 312 Crossing the Yellowstone River at Huntley, MT



USGS 06214500 Yellowstone River at Billings MT



- Daily mean discharge
- Estimated daily mean discharge
- Period of approved data

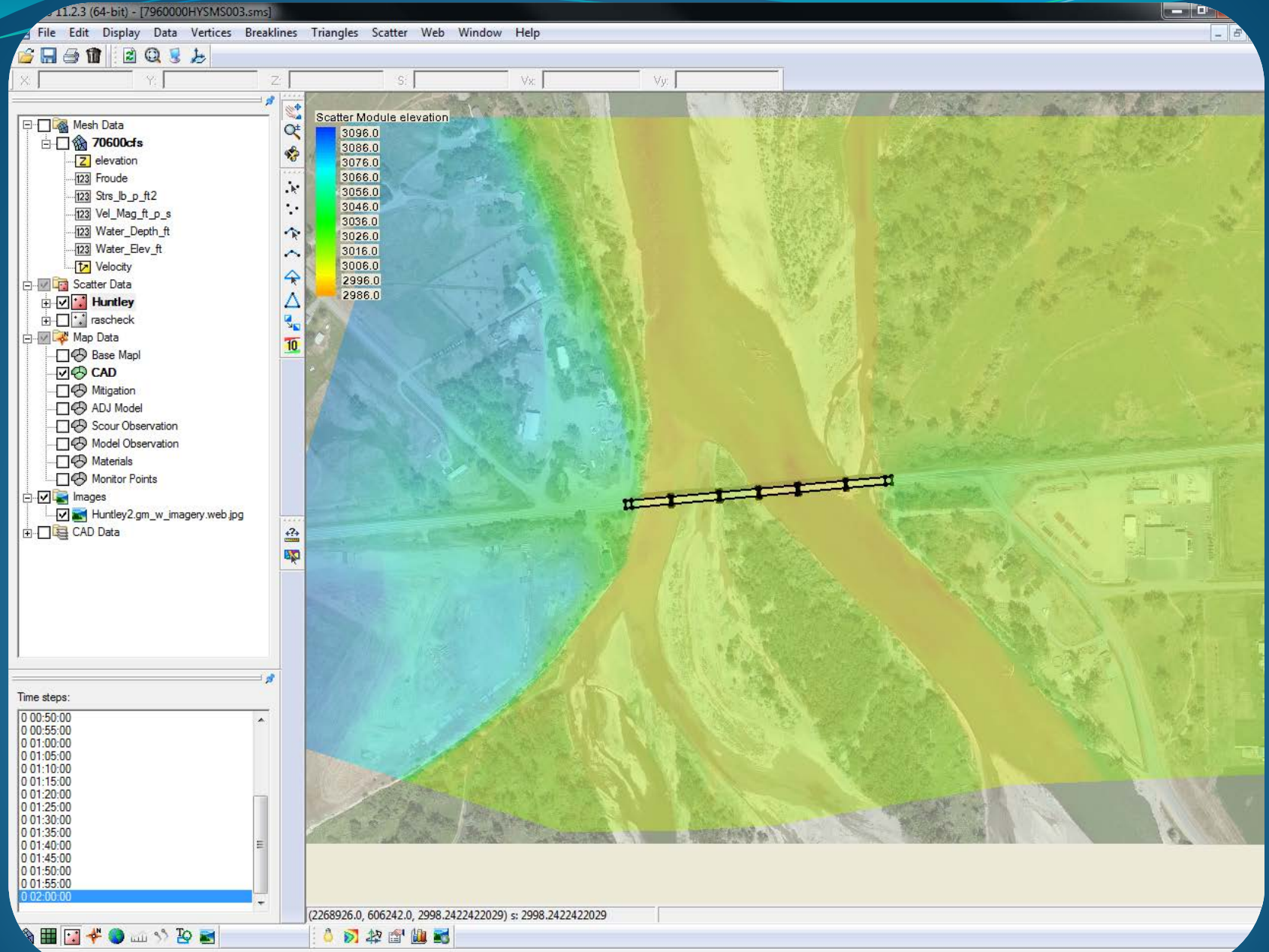
Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

Determine Mechanisms of failure:

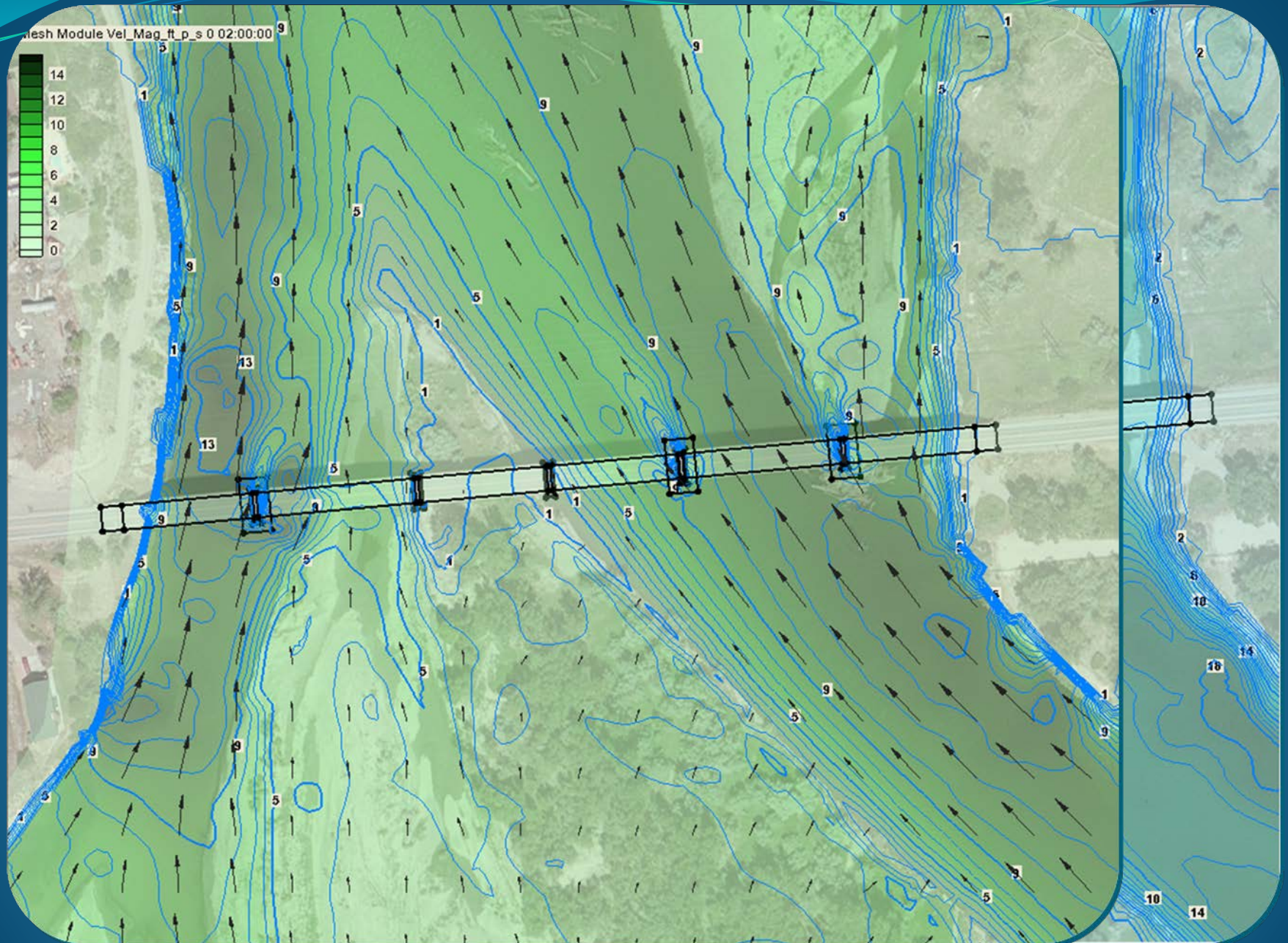
- Design Features
 - Review Plans
- Construction Techniques
 - Review Methods of Construction
- Data Requested
 - Bathymetric Survey
- Hydraulic Forces
 - Flood Flow
 - Hydraulic Modeling



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT



US Highway 312 Crossing the Yellowstone River at Huntley, MT



US Highway 312 Crossing the Yellowstone River at Huntley, MT

CTB DESIGN [Compatibility Mode] - Microsoft Excel

File Home Insert Page Layout Formulas Data Review View

Clipboard Font Alignment Number Styles Cells Editing

L30 $f_x = +L29/L28$

Block Dimensions	Channel Properties
height of block h = 0.63 ft	Slope of Energy Gradeline or Channel Slope = 0.0026 ft/ft
length of block l = 1.75 ft	Channel Velocity 13.5 ft/sec
width of block w = 1.75 ft	ΔZ 0.1667 ft
Area of block exposed = 3.0625 ft ²	C 0.5000
Unit weight of water γ_w = 62.4 lb/ft ³	F_D 51.56 lbf
Submerged unit weight of block W = 104.61 lbf	F_L 51.56 lbf
Density of Water ρ = 1.94 slugs/cuft	$W * h/2 * \sin(\theta)$ 0.2380 ft-lbf
Dynamic Viscosity of Water μ = 0.0000234 lbf*s/sqft	M_O 77.838 ft-lbf
θ = 0.1490	M_R 91.53 ft-lbf
$\sin(\theta)$ = 0.0026	FS 1.2
$\cos(\theta)$ = 1.000	

Drag Force $F_D = C * (\Delta Z * \rho * \omega * V^2)$

Lifting Force $F_L = F_D$

Momentum Transfer Coefficient assumed to be 0.5 C

width of projection ω

Maximum velocity block may be exposed to V

Moment resisting overturning (M_R) = $W * \cos \theta * (l/2)$ = Force * Length

Moment causing overturning (M_{OT}) = $W * \sin \theta * (h/2) + F_D * h + F_L * (l/2)$ = Force * Length

Factor of Safety Against Overturning (FS) = M_R / M_{OT}

$\tan^{-1}(S) = \theta$

System of Units Eng

Flow depth and EGL slope are based on design flow data
Assuming a perfect Installation

Assuming a projecting block height of 2.0 in

Assuming a projected block height of 2-in.

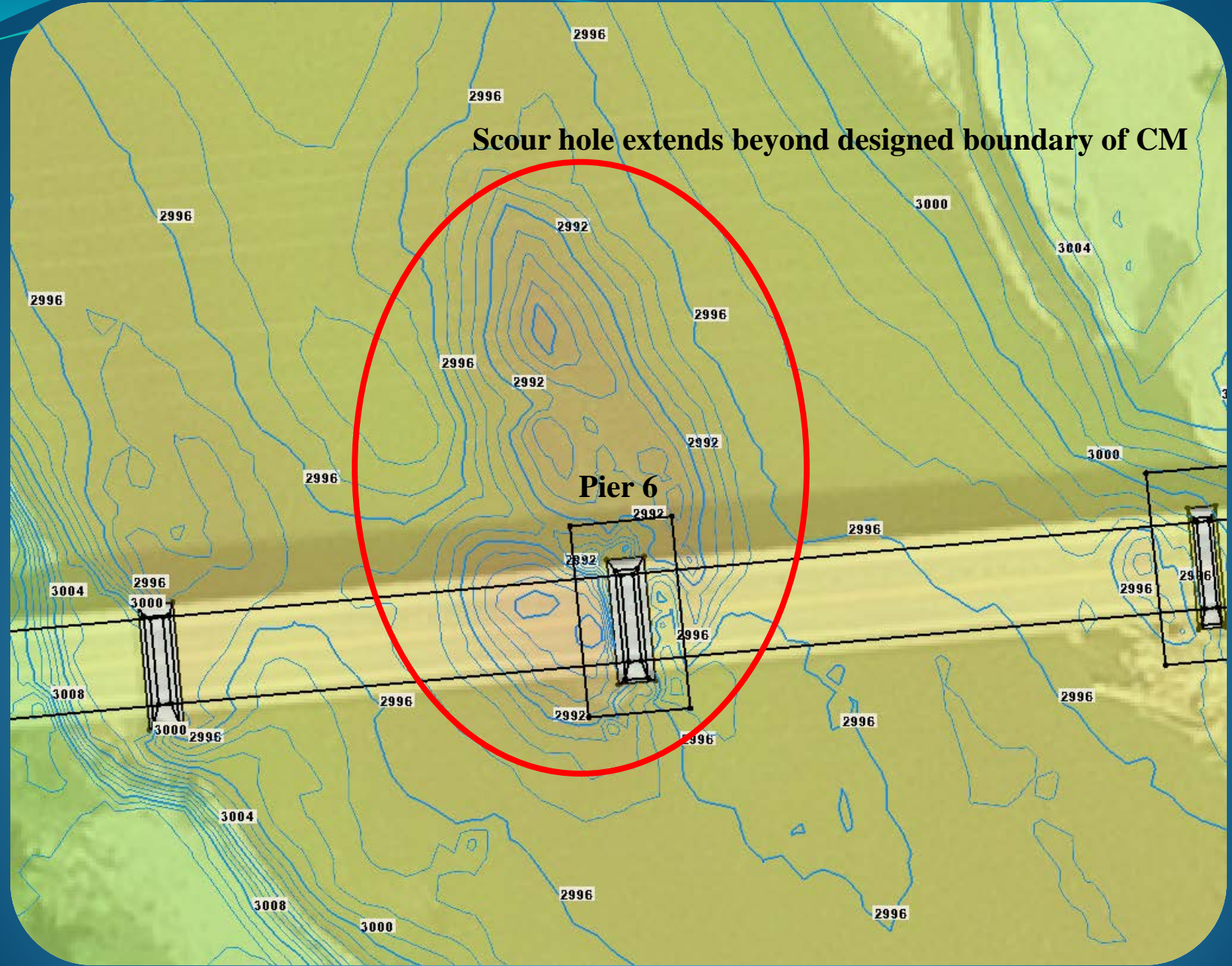
The safety factor for the ACB mattress is 1.2

Yellow Cells are input cells
Blue Cells are calculated Values USER must verify.

DISCLAIMER FS Shear = gamma R S CTB Factor of Safety Analysis



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

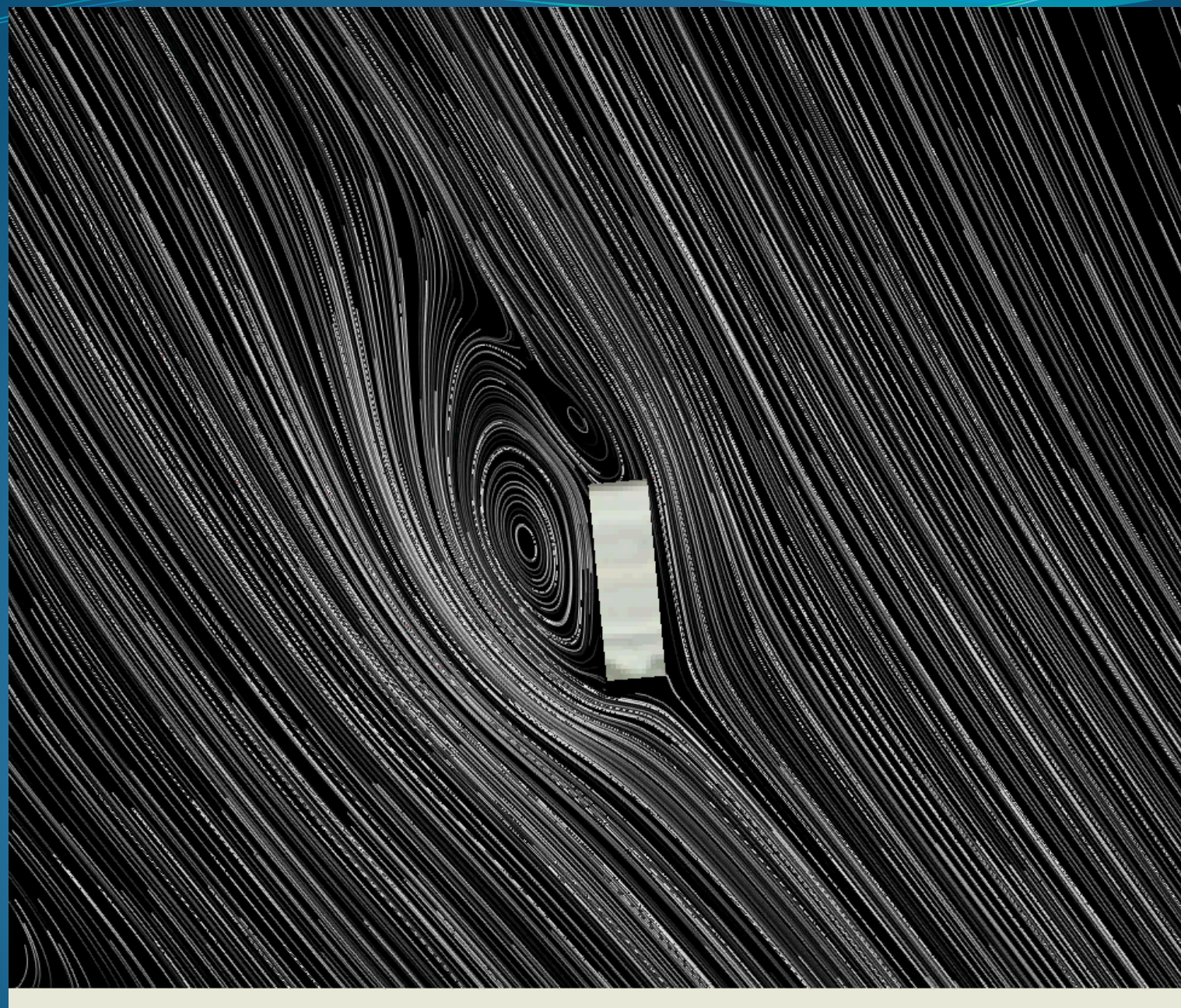


Scour hole extends beyond designed boundary of CM

Pier 6



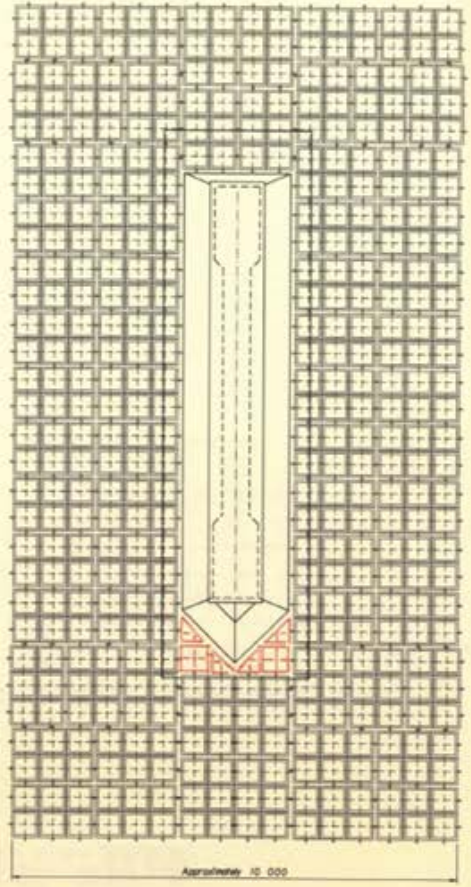
Old US Highway 312 Crossing the Yellowstone River at Huntley, MT



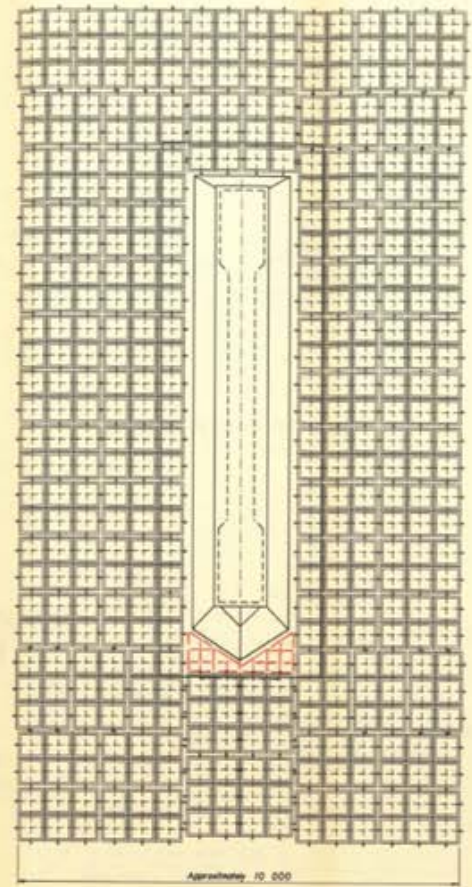
Old US Highway 312 Crossing the Yellowstone River at Huntley, MT



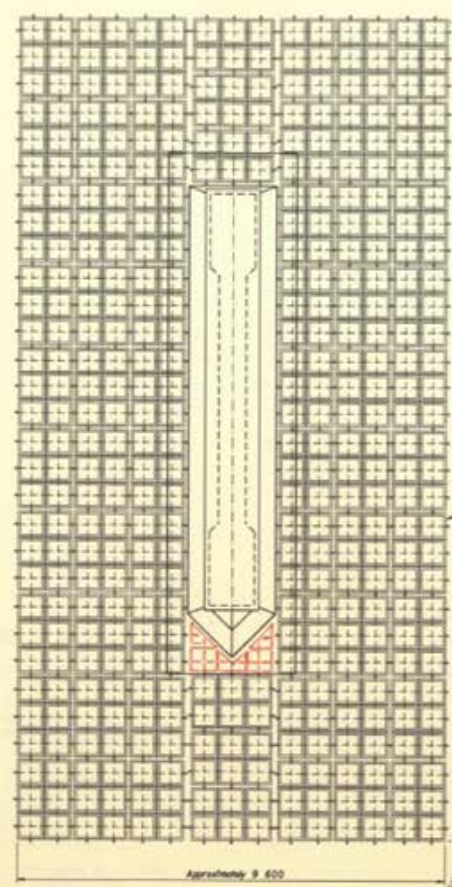
STATE	PROJECT NUMBER	SHEET NO.
MONTANA	BH 0002(745)	83



EXAMPLE BLOCK LAYOUT (PIER NO. 3)



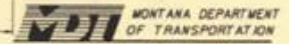
EXAMPLE BLOCK LAYOUT (PIER NO. 6)



EXAMPLE BLOCK LAYOUT (PIER NO. 7)

Cable to
deck surface
(Typ.)

Approximately 18 700
(Typ.)



MONTANA DEPARTMENT
OF TRANSPORTATION

BRIDGE OVER YELLOWSTONE RIVER
NEAR HUNTLEY
FEDERAL AID PROJECT NO. BH 0002(745)

YELLOWSTONE COUNTY
MATTRESS LAYOUT

Scale - 1 : 50

DESIGNED	8-7-03	R. J. B.
DRAWN	12-19-03	D. W. C.
CHECKED	8-22-03	J. S. G.
REVIEWED		
REVISIONS		

FILE NAME: 46788Perry2.dgn DRAWING NO. 19418

NOTE: Mattress cable that back mattress
to 10' pier as shown.

BY: J. S. G. / J. S. G. / J. S. G.
DATE: 12-19-03 / 12-19-03 / 12-19-03
PROJECT: BH 0002(745) / BH 0002(745) / BH 0002(745)

US Highway 312 Crossing the Yellowstone River at Huntley, MT

Contractors Solution

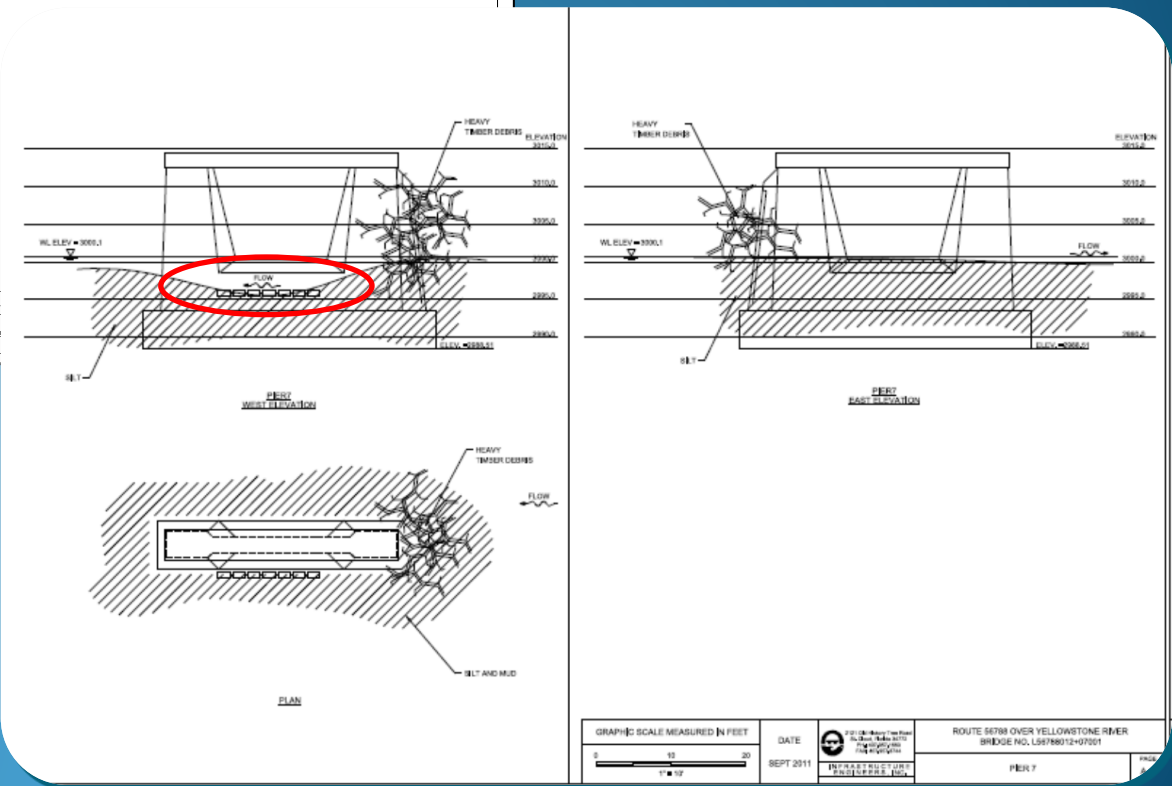
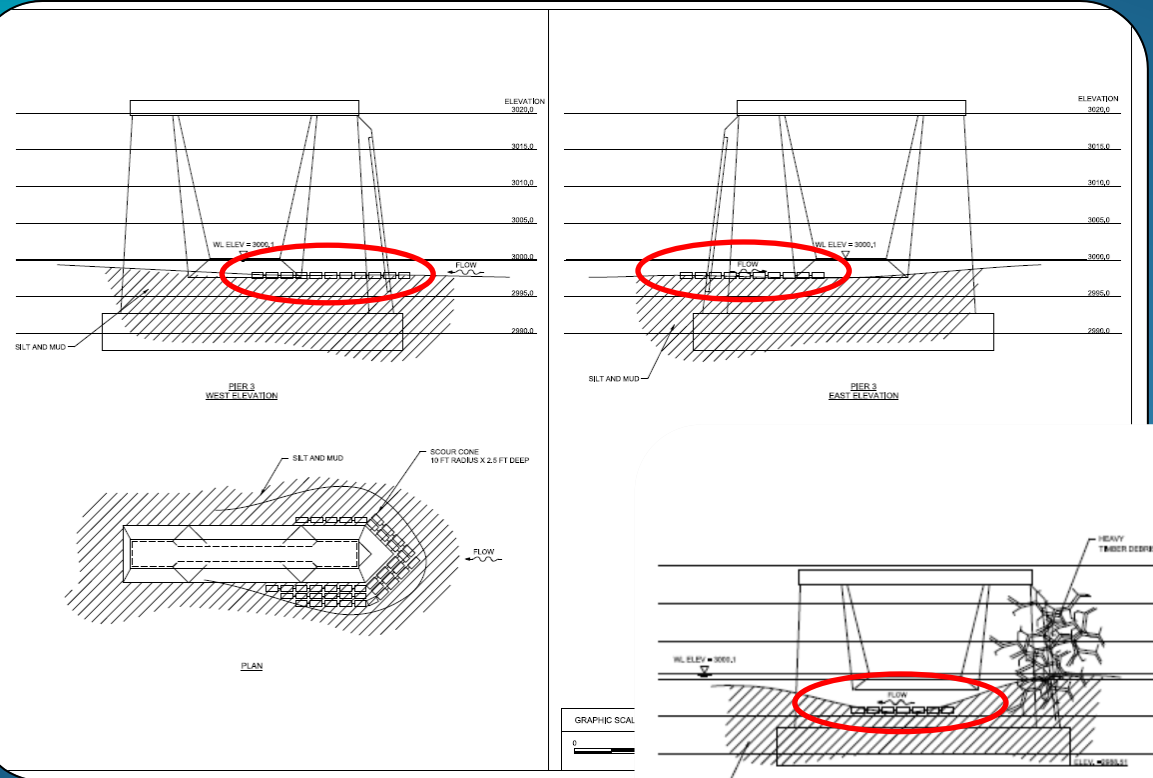
- Earthen Cofferdams
- Excavate to Depth



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

2011 Underwater Inspection report

Counter Measures were installed approximately 5-feet above footing at pier 3.

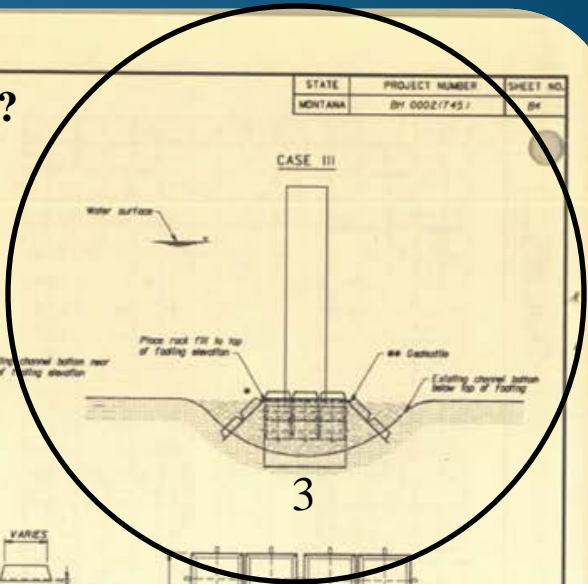
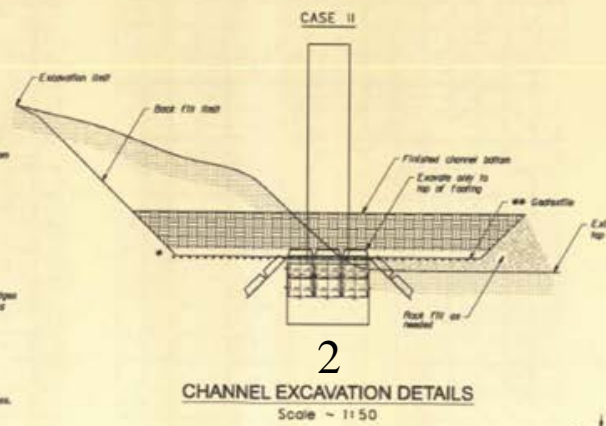
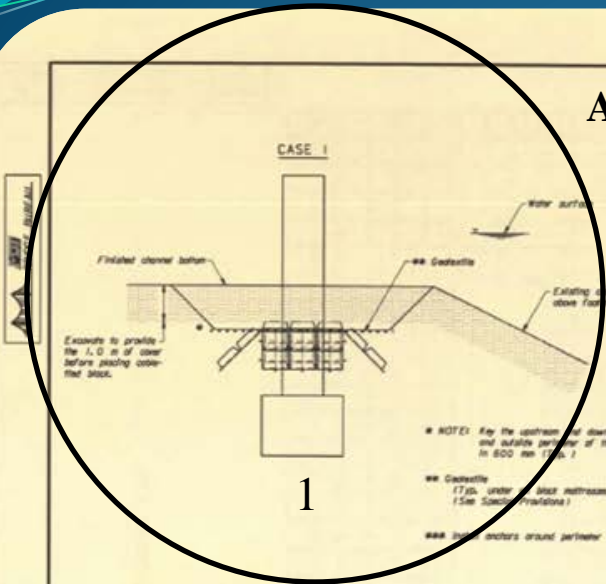


Counter Measures installed approximately 2-feet above the footing at pier 7.

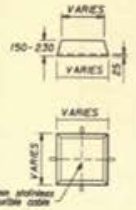
Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

ACB Mattress placement as intended?

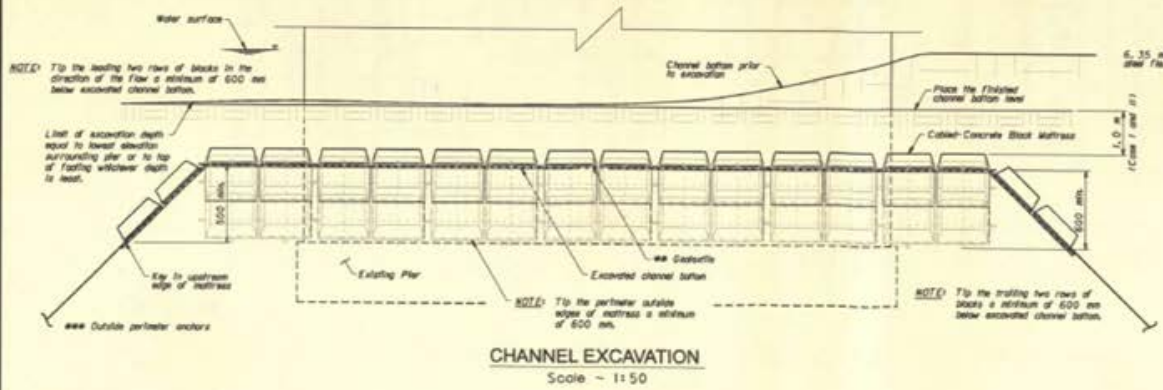
STATE	PROJECT NUMBER	SHEET NO.
MONTANA	BH 0002(1745)	BY



CHANNEL EXCAVATION DETAILS
Scale ~ 1:50



CABLED - CONCRETE BLOCK MATTRESS LAYOUT
Scale ~ 1:20



BRIDGE OVER YELLOWSTONE RIVER
NEAR HUNTLEY

FEDERAL AID PROJECT NO. BH 0002(1745)

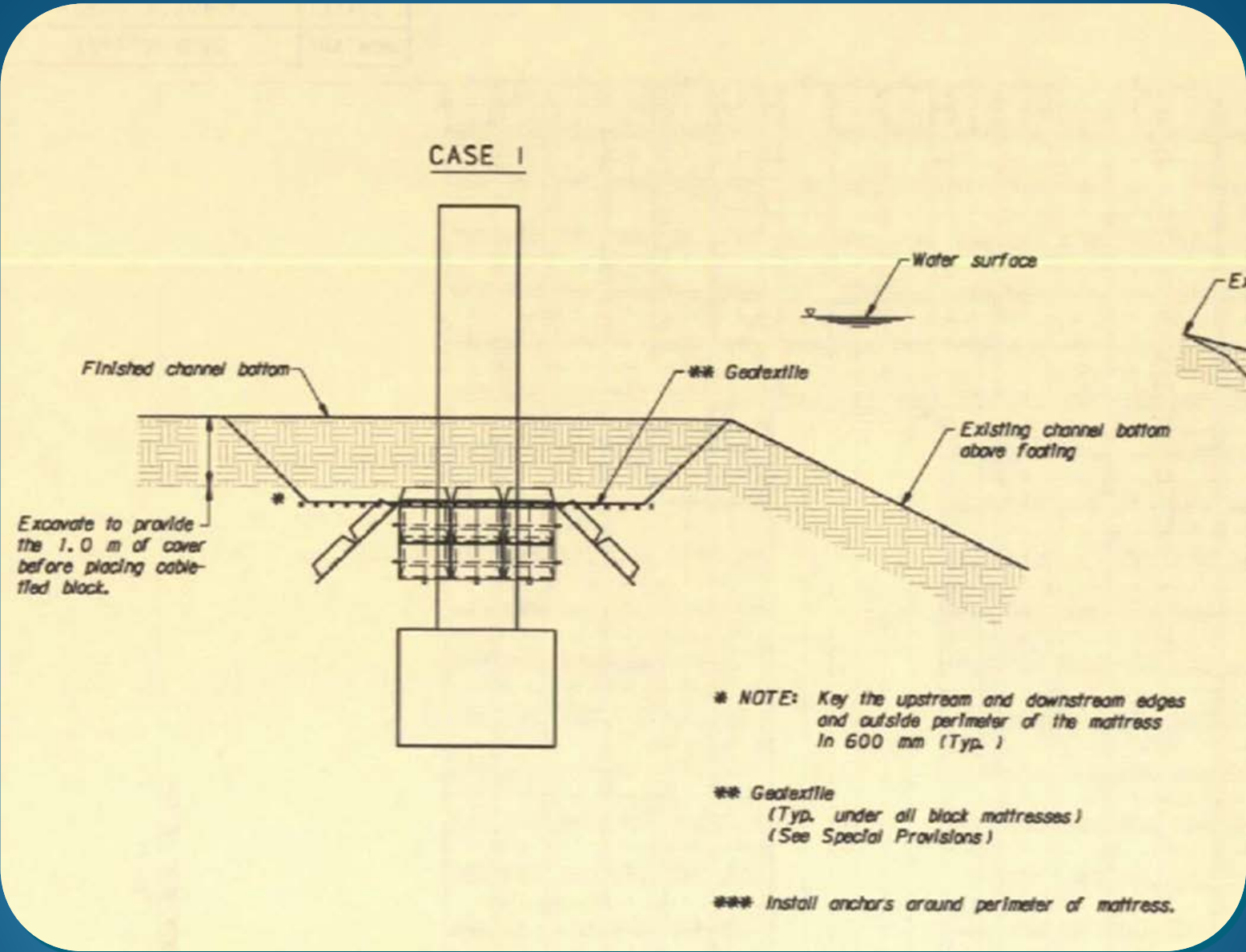
YELLOWSTONE COUNTY

MISCELLANEOUS DETAILS

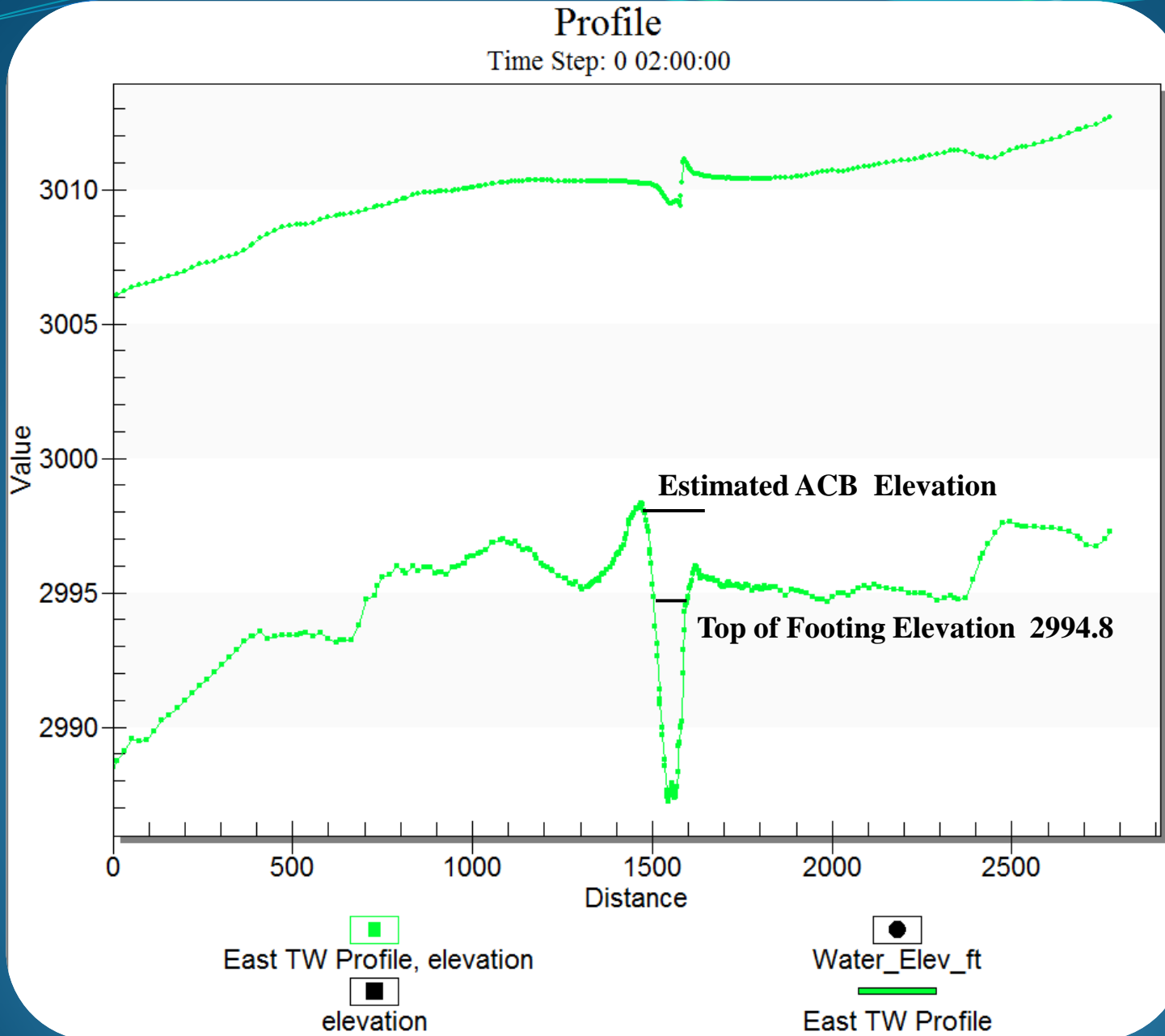
DESIGNED	P-3-DY	K.J.C.
DRAWN	12-19-03	D.W.C.
CHECKED	8-22-03	J.S.G.
REVIEWED		
REVISION		

11/1/2004 4:27 PM
10/17/2005
BY: 204 AB AB CYS - 10077

Old US Highway 312 Crossing the Yellowstone River at Huntley, MT



US Highway 312 Crossing the Yellowstone River at Huntley, MT



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

Conclusion:

➤ ACB Failure combination of factors.

- Minimal Survey
- ACB Elevations not specified
- Plan Interpretation
 - Contractor
 - Construction PM
 - Designer
- ACB's placed above channel thalweg.
- Material beneath ACB mobile and likely washed away.
- Experience



Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

LESSONS



LEARNED

➤ Initial Site Survey/Evaluation

- Better description of what is going on underwater.
- Aid in CM Selection process.
- Allow for more detailed hydraulic modeling
- Allow for better plan preparation

➤ Design

- Define final elevations of countermeasures.
- Extend depth of mattress “key” to minimum of exposed Footing Height.

➤ Construction

- Technique and Experience
- Plan Interpretation
- Better communication
 - Construction Project manager
 - Design Engineer
 - Contractor.

Old US Highway 312 Crossing the Yellowstone River at Huntley, MT

