Scour Monitoring & Prediction

From Simple to Sophisticated Schemes

2010 Western Bridge Preservation Partnership
Sacramento, California

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Caltrans
Structure Maintenance & Investigation
Hydraulics Branch

Caltrans

Outline

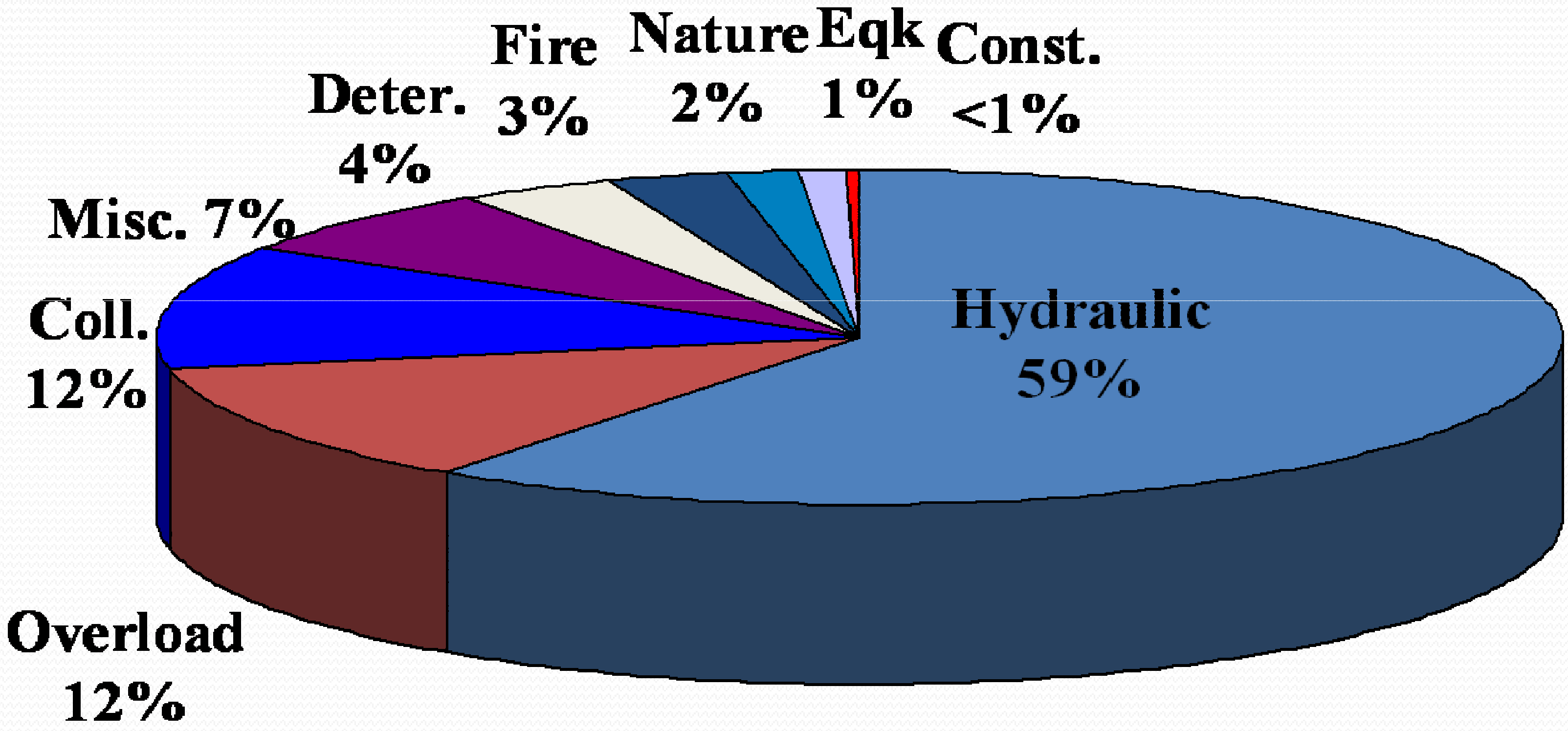
Importance of Visualizing Channel Cross-Sections

- BrEase – a simple, but powerful tool

Monitoring and Prediction of Scour

- Full-scale Surveys
- Use of Areal Photographs
- 2-Dimensional Modeling
- Computational Fluid Dynamics

1607 U.S. Bridge Failures Since 1950



1989 Hatchie River Bridge Failure in Western Tennessee

24 TRANSP

April 1989 Hatchie River US-51 Bridge Failure

PHILIP L. THOMPSON

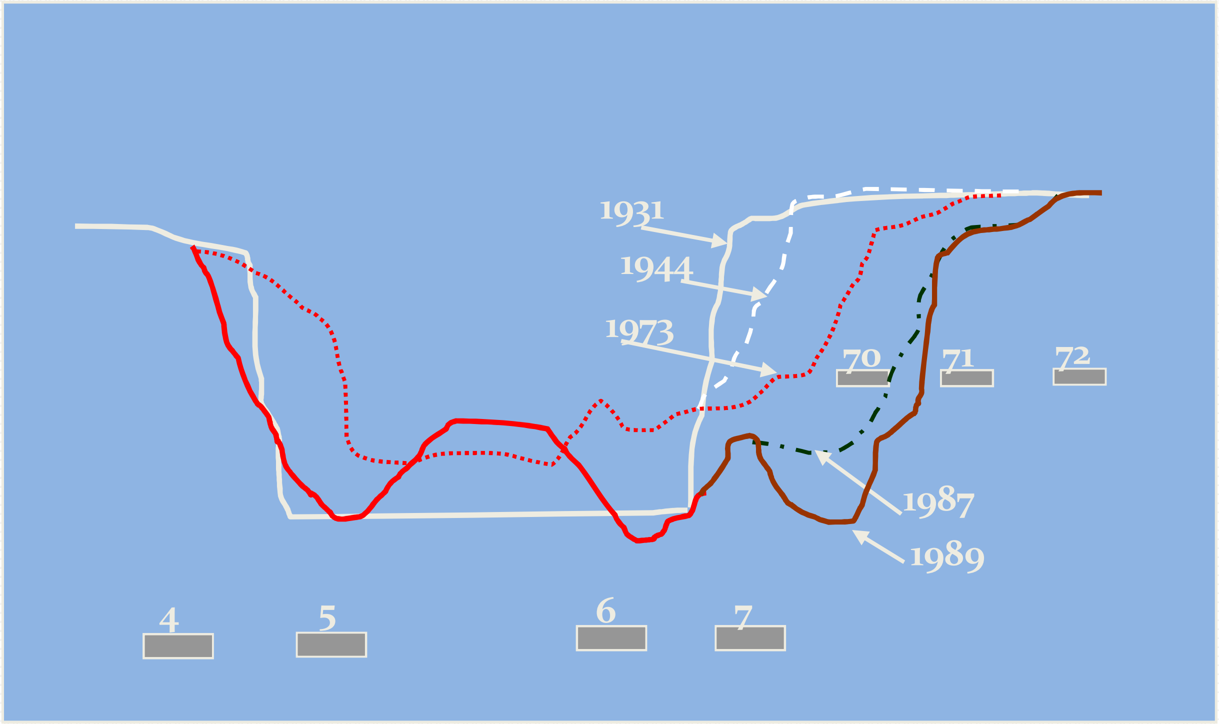
The FHWA assisted in the National Transportation Safety Board (NTSB) determination of the cause of the collapse of the spans of the northbound US-51 bridge over the Hatchie River on April 1, 1989. The collapse resulted in five vehicles going into the river and eight people being killed. The bridge site, field observations, stream stability, analysis of aerial photographs, model studies, and foundation analysis are discussed.

FIELD OBSERVATIONS

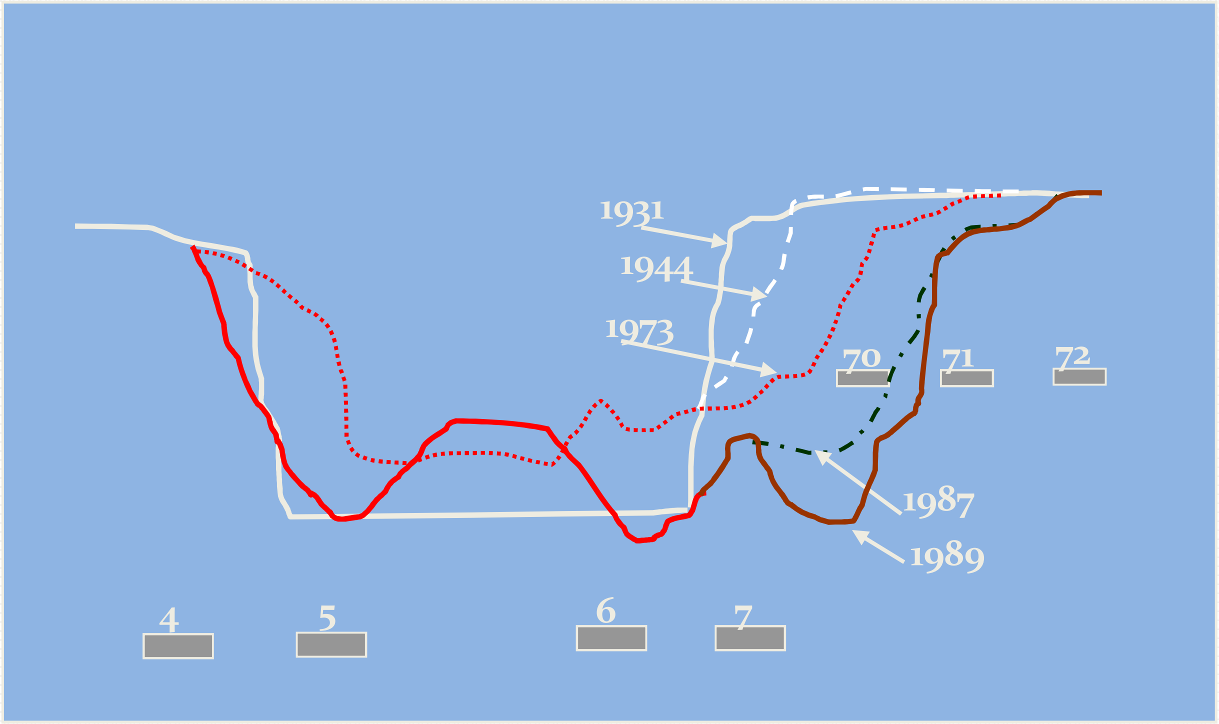
The author and J. Sterling Jones of the FHWA were on the site during the week beginning April 3, 1989. They participated in all phases of the investigation with Joseph Osterman, NTSB investigator-in-charge, and Lawrence E. Jackson, NTSB

3 Spans Collapsed 5 Vehicles in the River 8 Lives Lost

Channel Migration



Channel Migration



3 Findings & Recommendations

FINDING #2. Sounding data were taken for all piers in the channel during regular inspections.

However, this information was not transferred to a cross-section plot which included pier location and foundation elevations.

RECOMMENDATIONS.

- A cross-section of the channel should be plotted after each inspection.
- The plot should include appropriate substructure information
- The cross-section should be compared to those taken in previous years so that stream changes can be identified.
- If movement has occurred, it should be assessed by a Hydraulic Engineer

BrEase

A Tool for Stream Stability and Scour Assessment

H$_2$FLO Consulting
www.h2floconsulting.com

What is BrEase?

- An engineering tool to
  1. Monitor stream stability
  2. Estimate hydraulic conditions
  3. Perform scour calculations

- An Application of Microsoft Excel
- Automated with Visual Basic Code and User Input Dialog Boxes

BrEase History?

- Program Developed in 1997 for Oregon DOT to analyze and document Stream Stability and as a Key Component for their Scour POAs
- Used as Integral Part of Caltrans Scour Evaluation Program since 1998
- Current Release in 2010 is Version 3.4

Goal 1: Accurate Plot of Channel Sections and Bridge Items

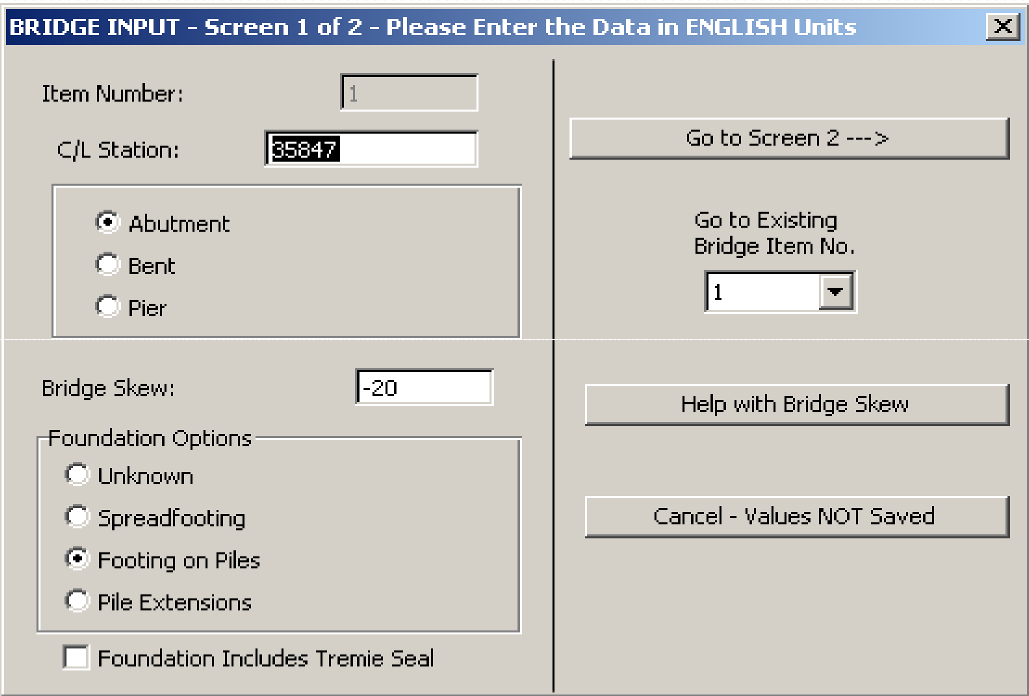
<u>Bridge Geometrics</u>

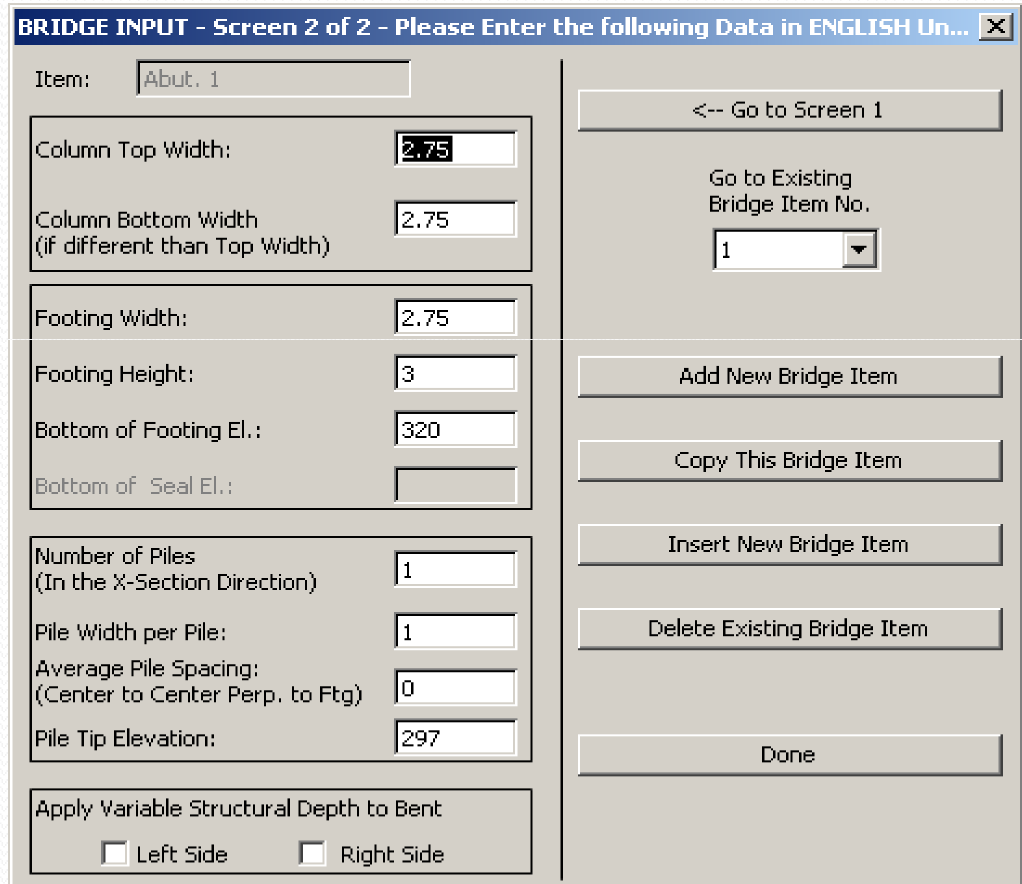
- Bridge Vertical Alignment
- Deck Cross-Slope
- Substructure Elements to Drawn to Scale

<u>X-Section Calculations</u>

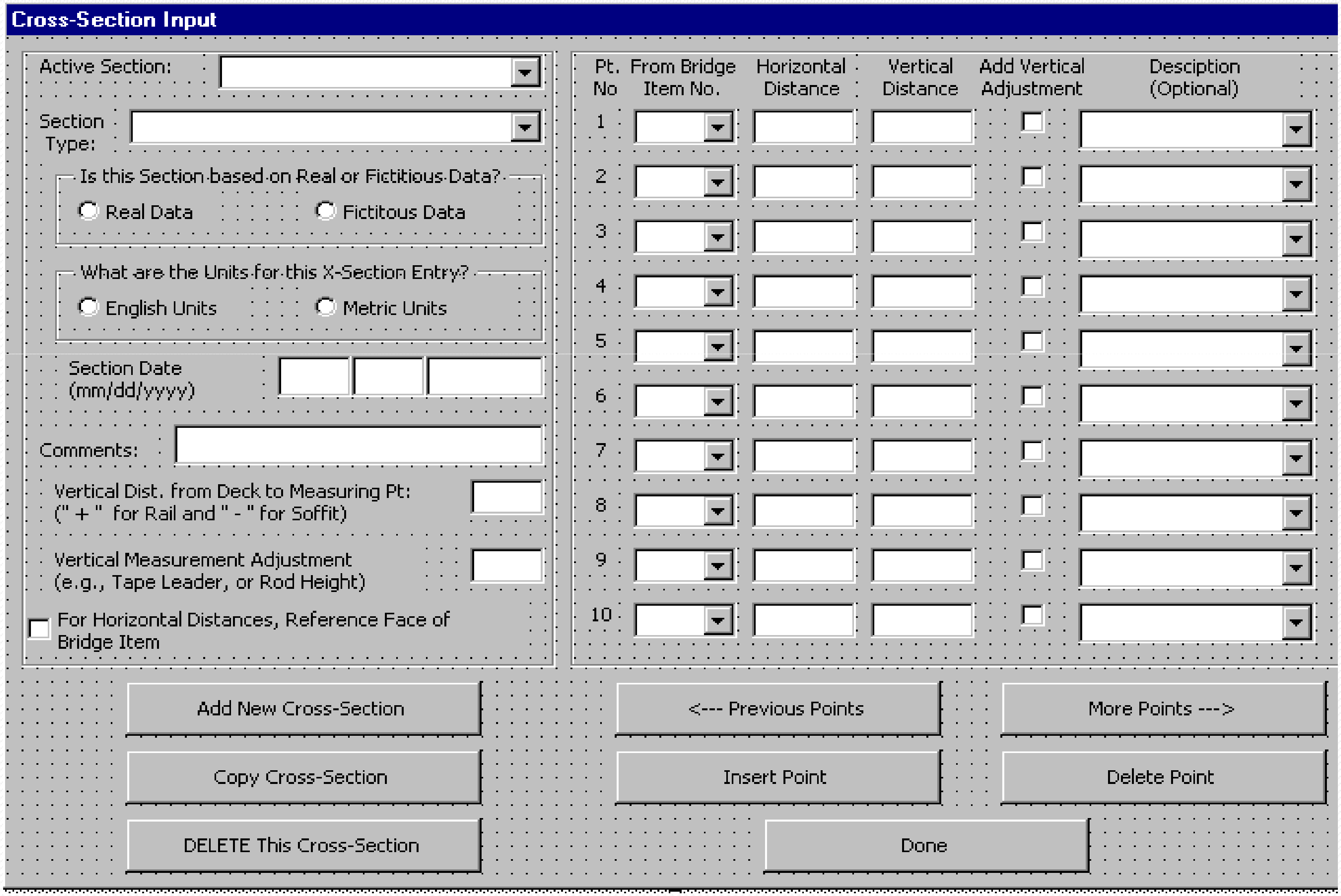
- Subtracts for Vertical Reference Points
- Adjusts Channel for Tape/Rod Offsets
- Multiple Horizontal Reference Points

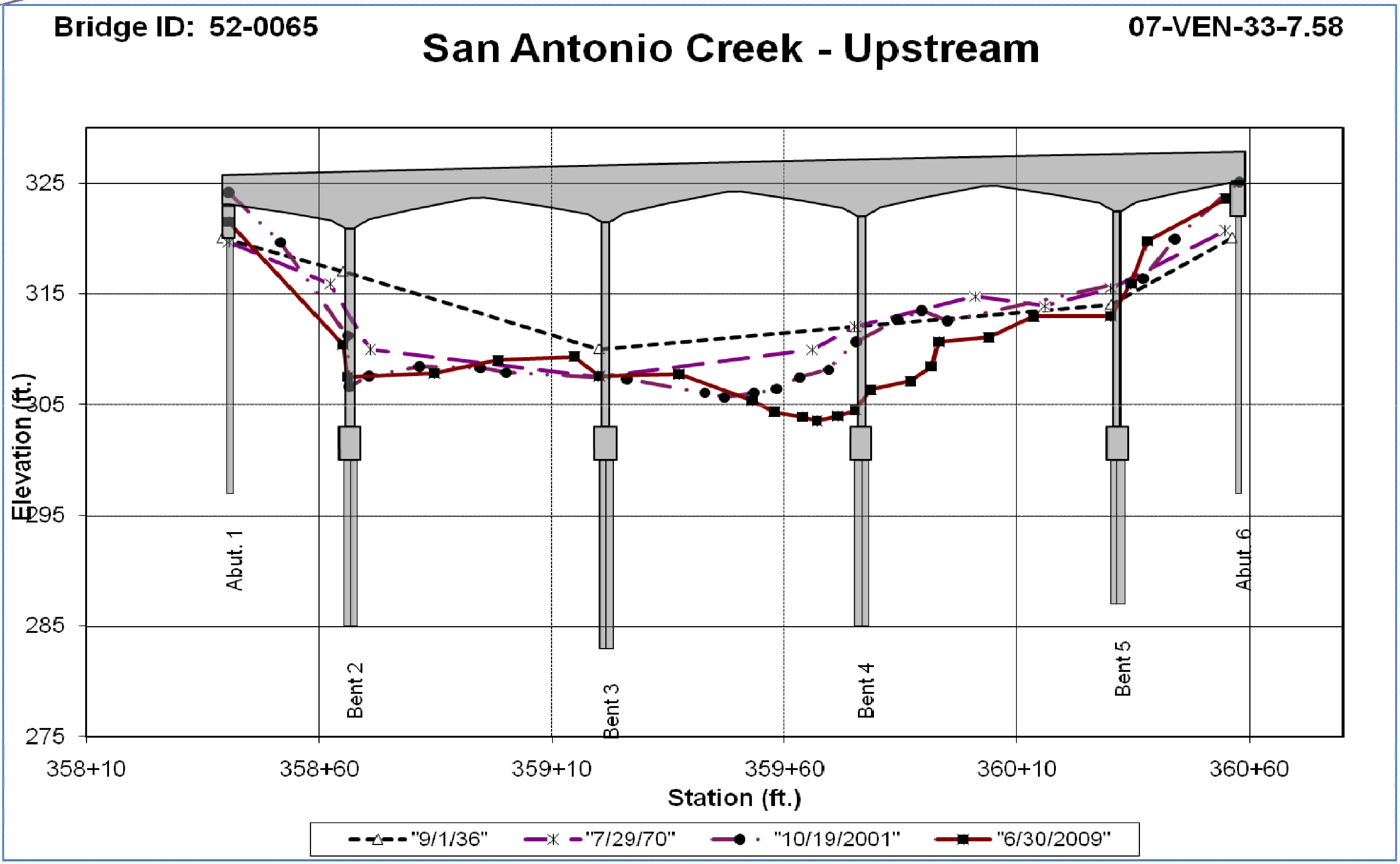
Bridge Geometric Inputs





Channel X-Sections Input





Bridge ID: 52-0065
San Antonio Creek - Upstream
07-VEN-33-7.58
Elevation (ft.)
325
315
305
295
285
275
Abut. 1
Bent 2
Bent 3
Bent 4
Bent 5
Abut. 6
358+10
358+60
359+10
359+60
360+10
360+60
Station (ft.)
"9/1/36"
"7/29/70"
"10/19/2001"
"6/30/2009"

Goal 2: Quick Hydraulic Analysis

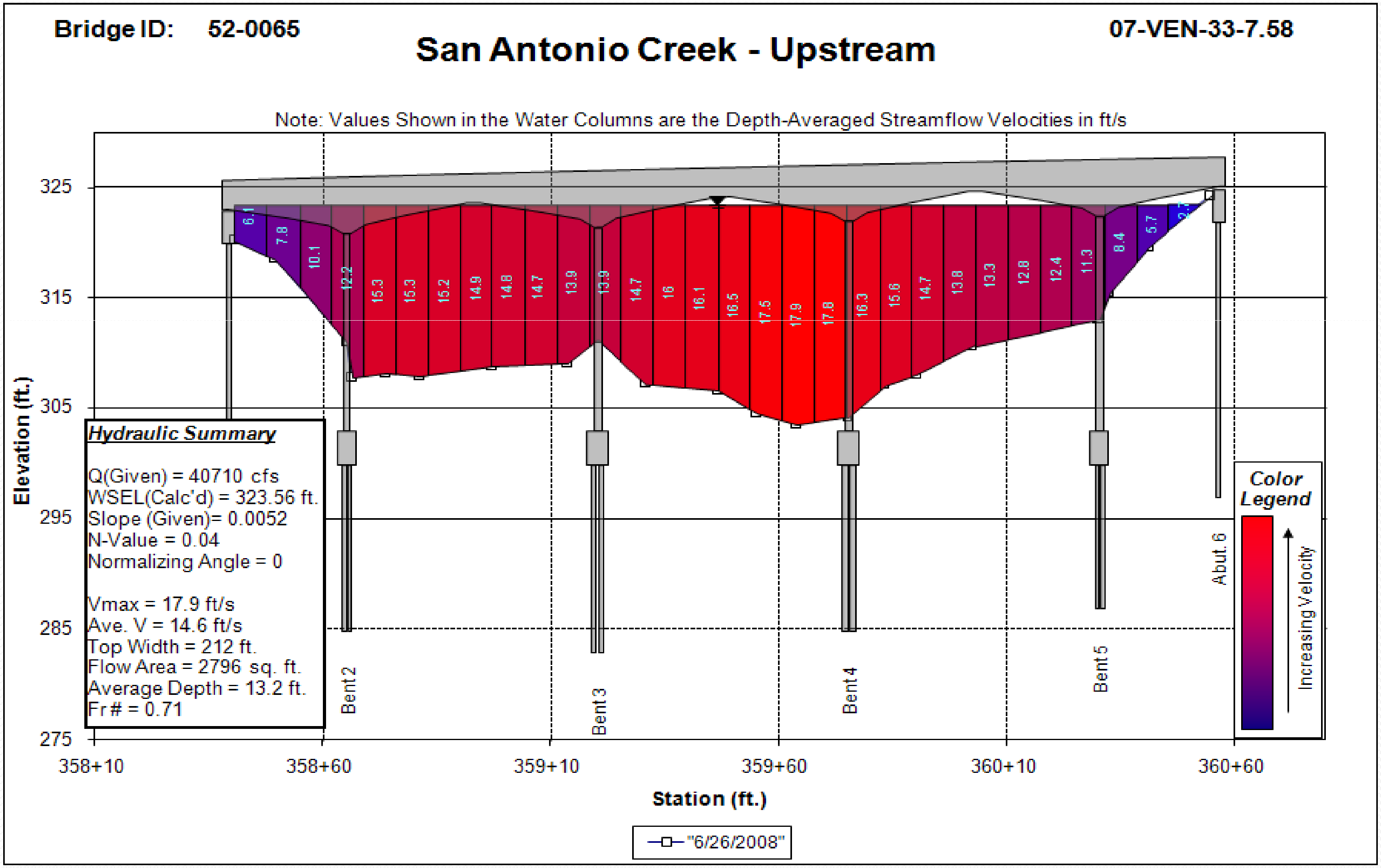
<u>Analysis</u>

- “Idealized” Uniform Flow Assumption
- Single Cross-Section
- Basic Hydraulic Parameters :
  - Slope
  - Roughness
  - Discharge

<u>Benefits</u>

- Approx. 5% of personnel time compared to 1-D program
- Estimates Flow Velocities by Streamtubes
- Provides Alternative Calculations based on known data

Sample Hydraulic Plot

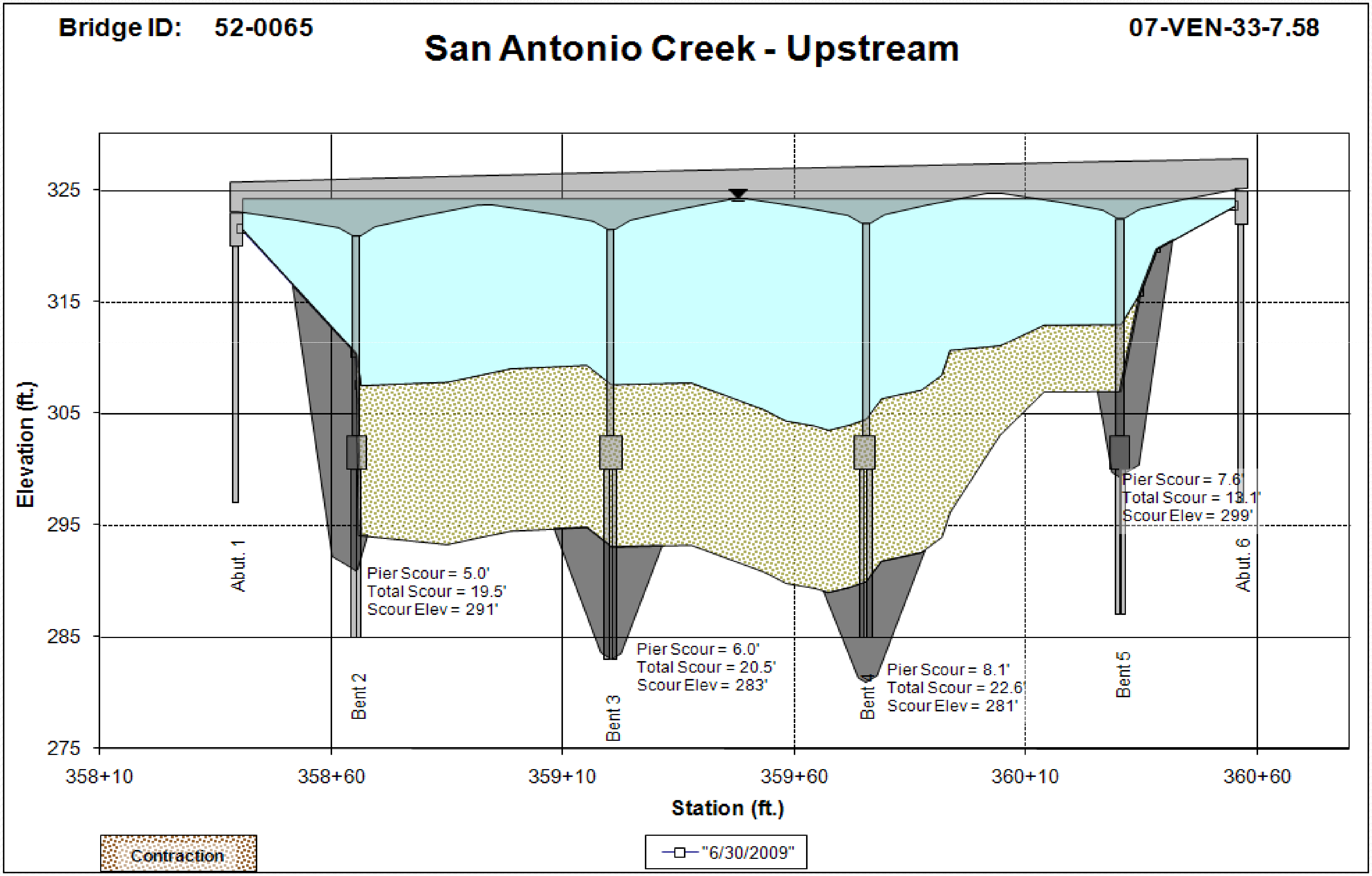


Goal 3: Robust Scour Analysis

<u>Scour Calcuations</u>

- Pier Scour (including Complex Pier Scour Calculations)
- Degradation Analysis
- Contraction Scour
- Pressure Scour
- Abutment Scour

Total Scour Chart



Case Studies with BrEase

- Case 1 - Migration of the Channel ➔ Potential Lateral Instability of the Bent Columns
- Case 2 – Degradation ➔ Undermining of Spreadfooting

Br. No. 08-0085 – Thomes Creek on Interstate 5 in Tehama County

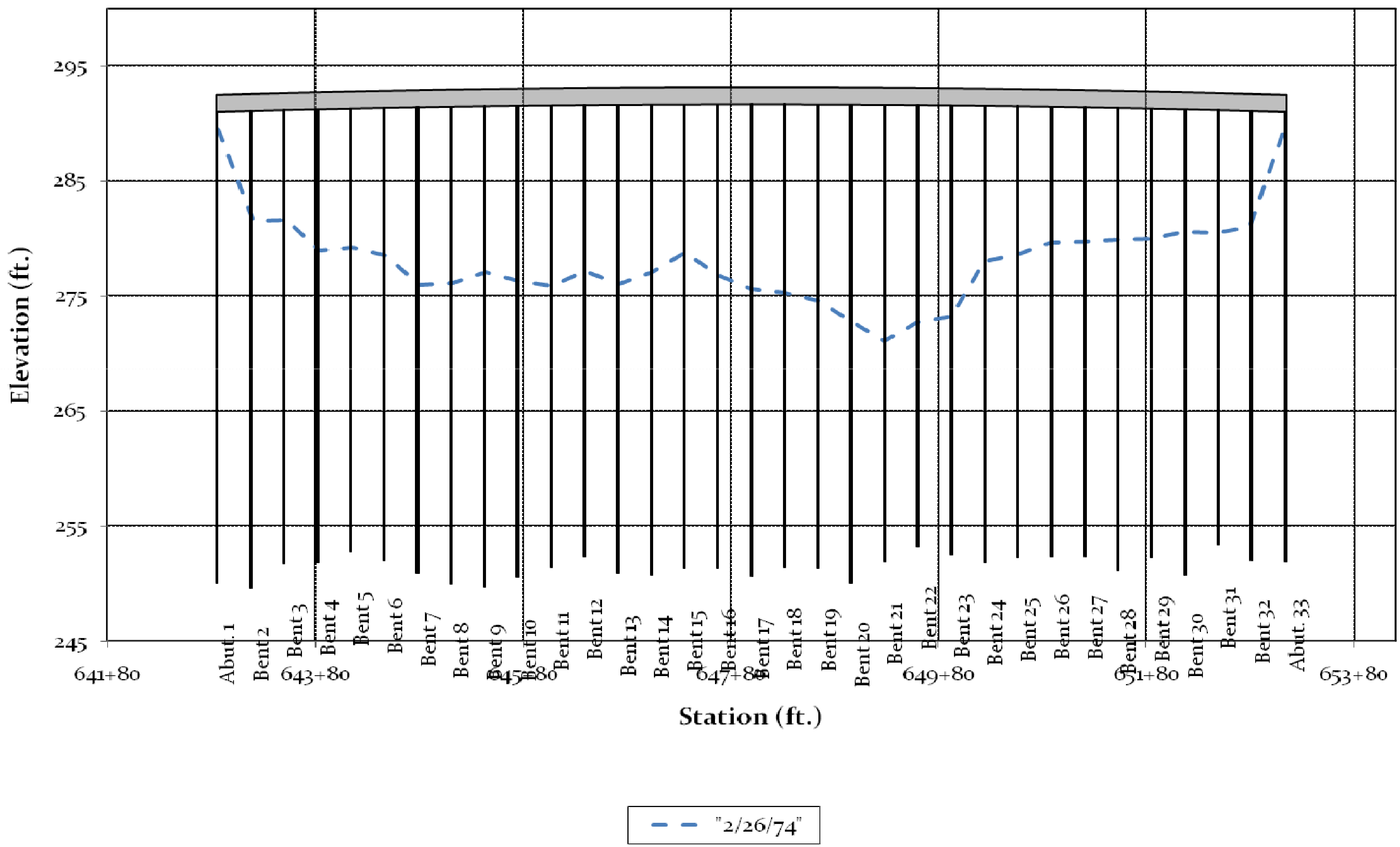
32 Span, Slab supported on Reinforced Concrete Pile Bents

Ongoing Bank Erosion Downstream

Bridge ID: 8-85L

Thomes Creek - Upstream

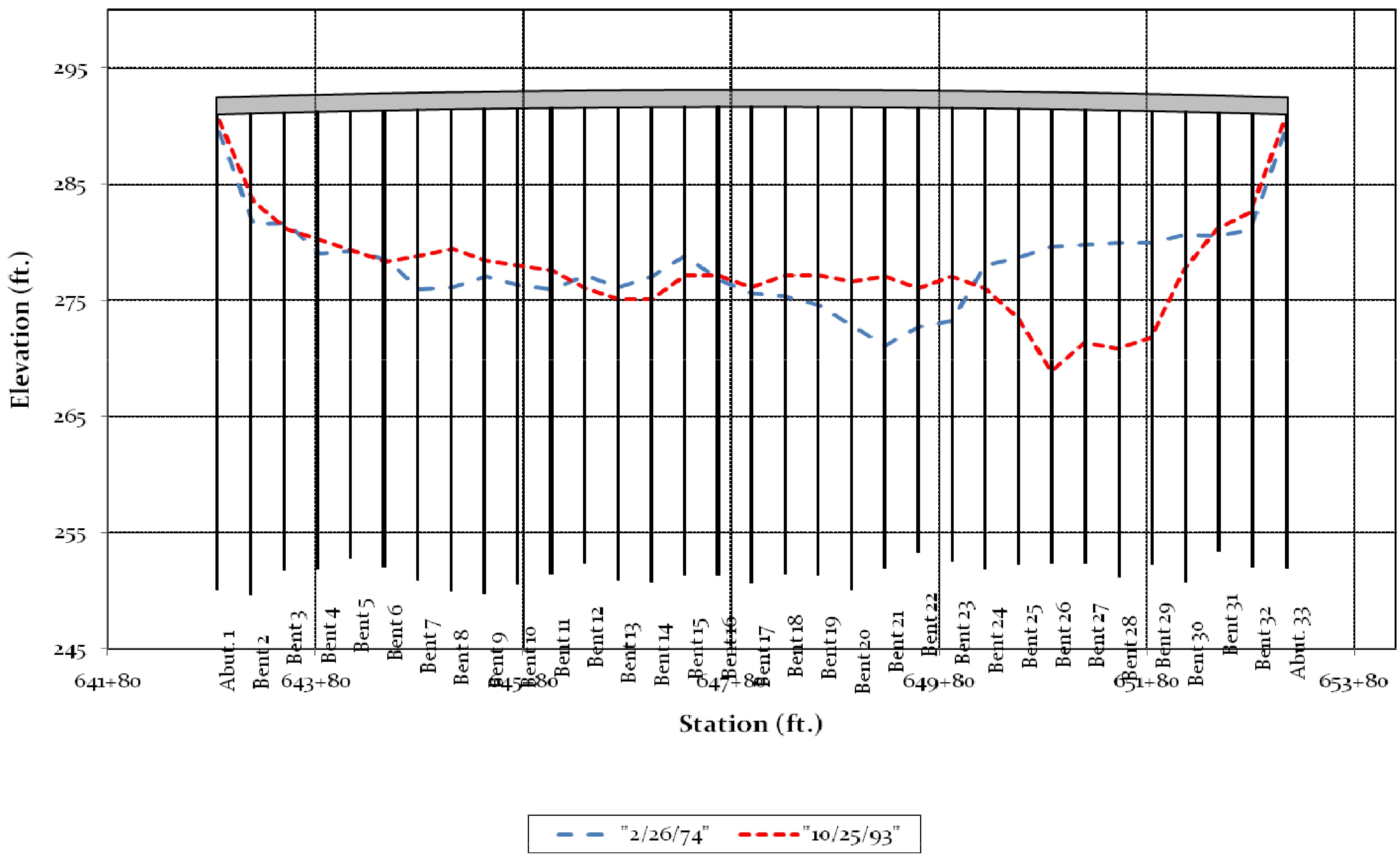
2-Teh-5-R12.35



Bridge ID: 8-85L

Thomes Creek - Upstream

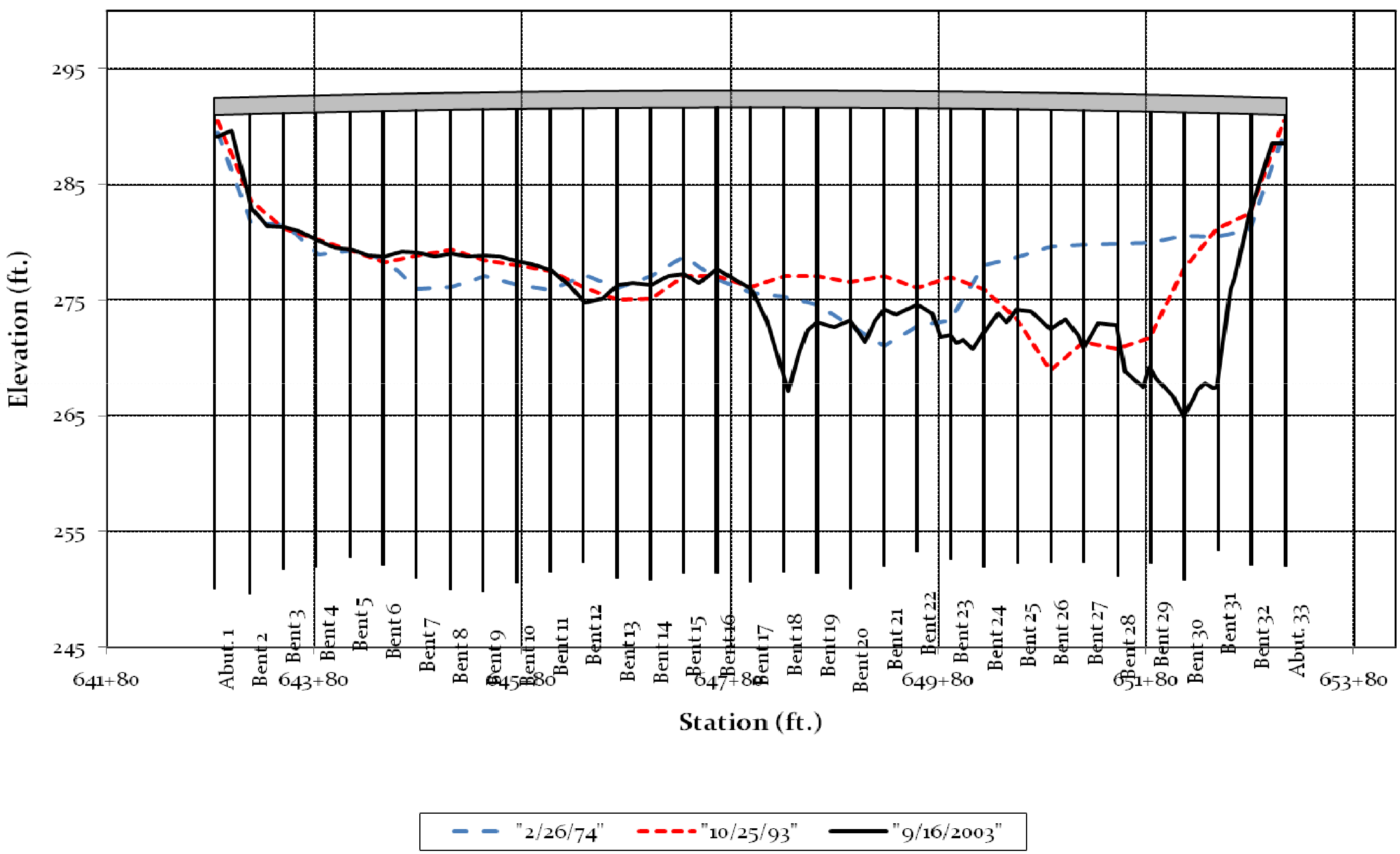
2-Teh-5-R12.35



Bridge ID: 8-85L

Thomes Creek - Upstream

2-Teh-5-R12.35



Scour Evaluation / Mitigation

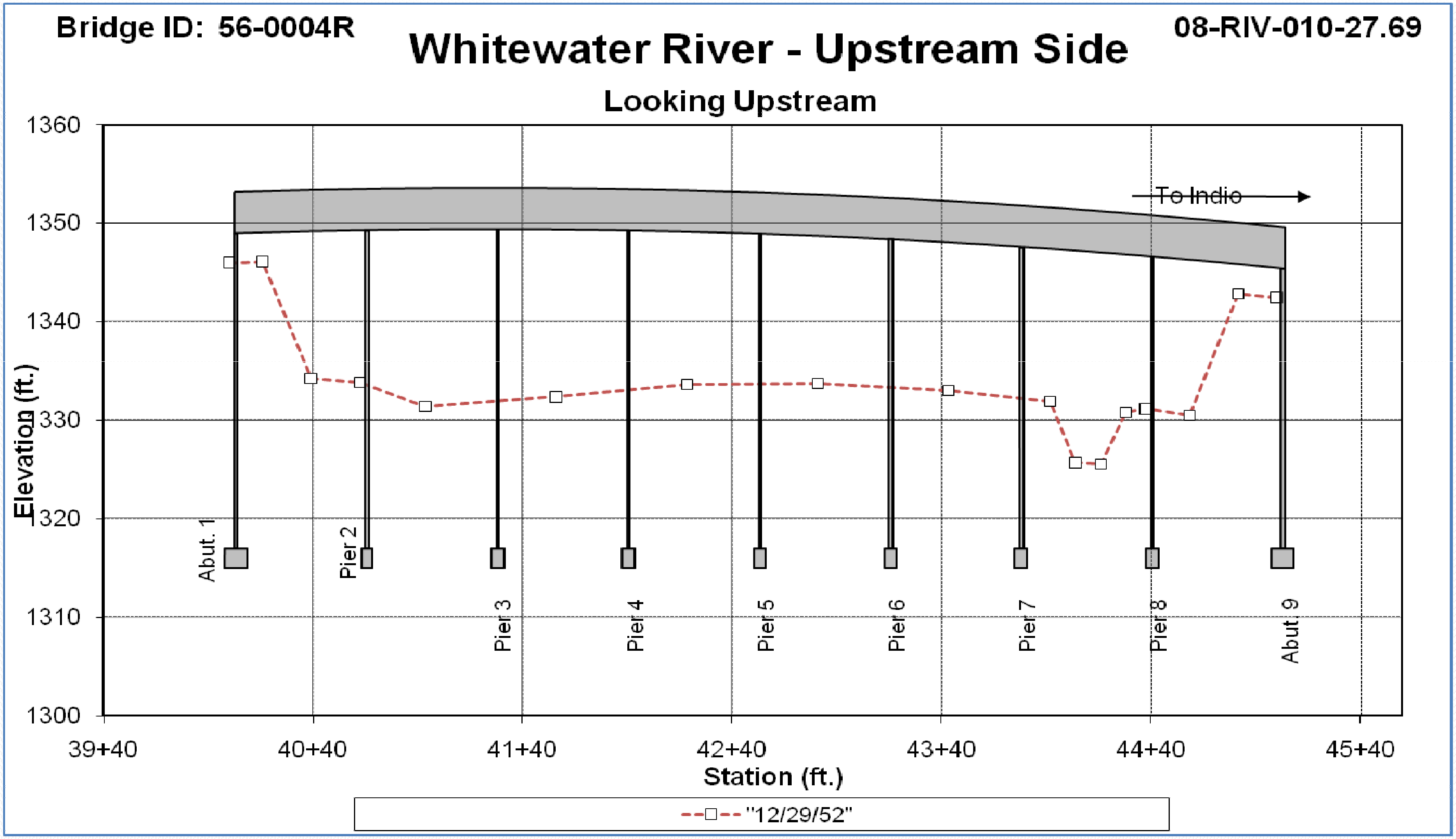
- Increased unbraced length at the column bents and potential scour made the bridge unstable
- Emergency Project to brace the columns was undertaken
- Long-term Solution: Bridge Replacement

Bracing of the Columns

Br. No. 56-0004R - Whitewater River near Palm Springs, CA

Aerial View

San Bernardino National Forest
Forest Falls
Morongo Valley
Big Morongo Canyon Preserve
Twentynine Palms Hwy
62
Desert Hot Springs
Banning
10
Redlands Fwy
Cabazon
Banning Municipal Airport
56 0004R
North Palm Springs
111
243
Racquet Club West
Desert Park Estates
Palm Springs
Palm Springs International Airport
Mt San Jacinto State Wilderness
San Jacinto

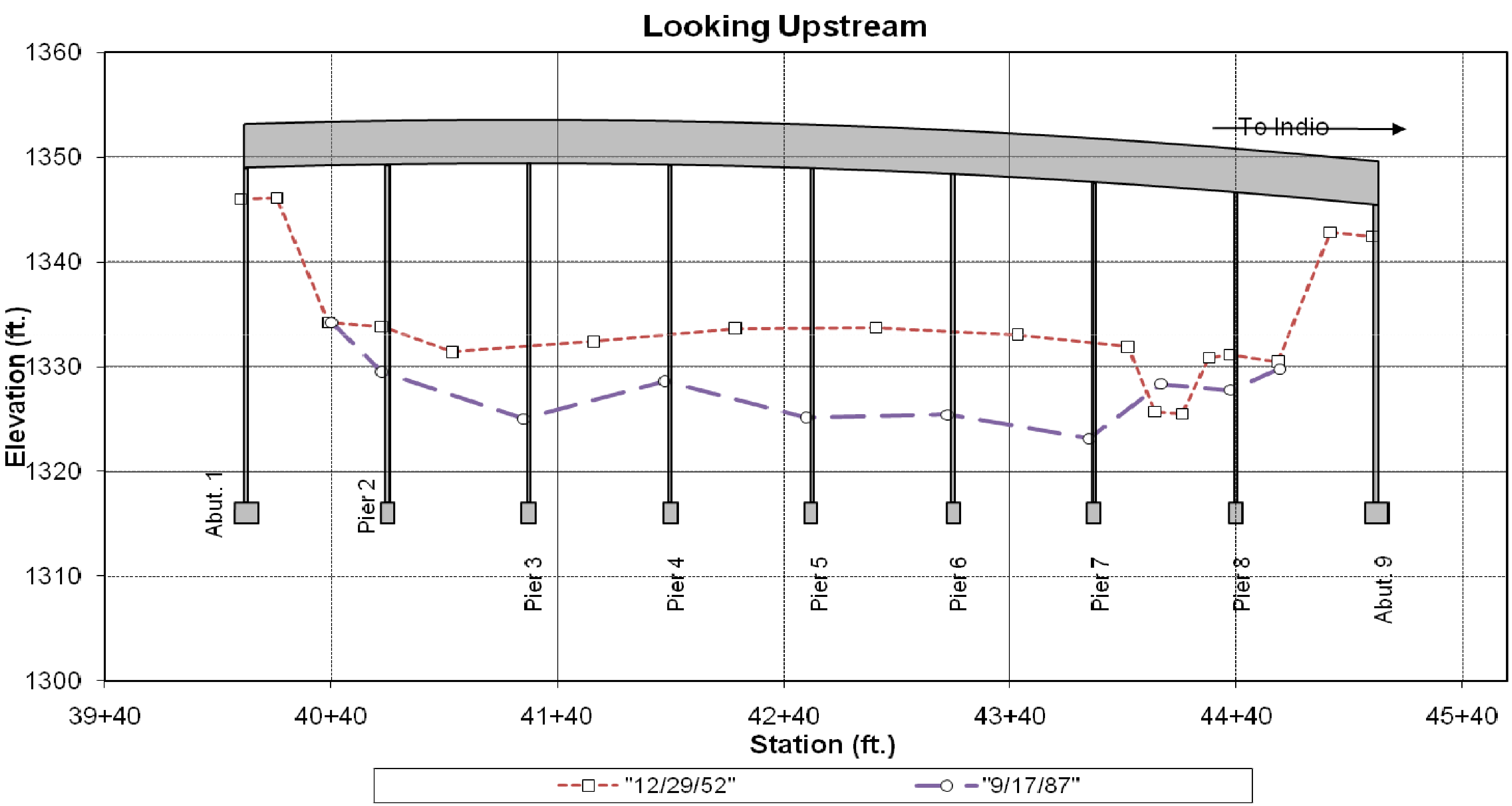


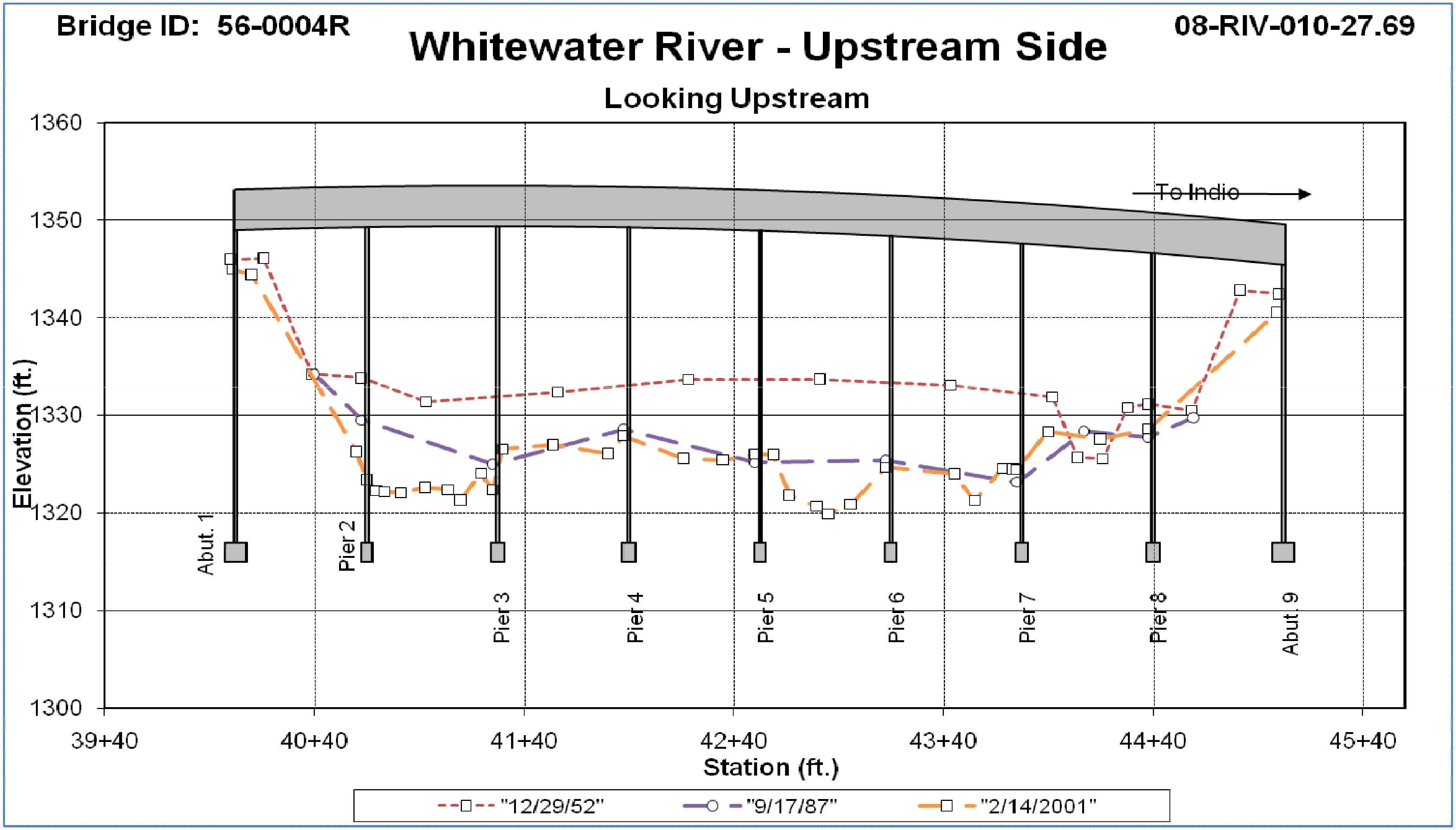
Bridge ID: 56-0004R
08-RIV-010-27.69
Whitewater River - Upstream Side
Looking Upstream
To Indio
Elevation (ft.)
1360
1350
1340
1330
1320
1310
1300
Abut. 1
Pier 2
Pier 3
Pier 4
Pier 5
Pier 6
Pier 7
Pier 8
Abut. 9
39+40
40+40
41+40
42+40
43+40
44+40
45+40
Station (ft.)
"12/29/52"

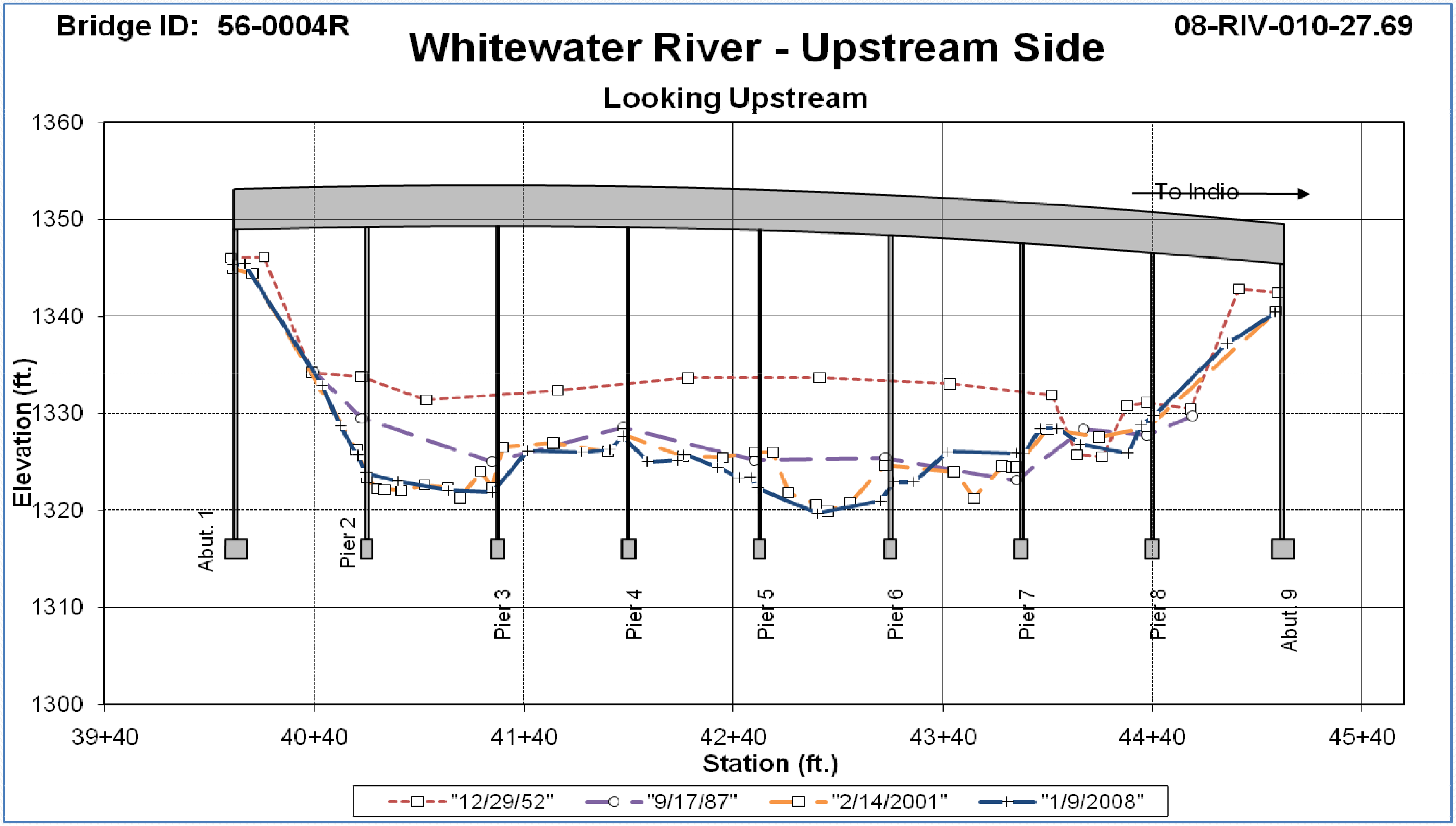
Bridge ID: 56-0004R

Whitewater River - Upstream Side

08-RIV-010-27.69




Bridge ID: 56-0004R
Whitewater River - Upstream Side
08-RIV-010-27.69
Looking Upstream
To Indio
Elevation (ft.)
1360
1350
1340
1330
1320
1310
1300
Abut. 1
Pier 2
Pier 3
Pier 4
Pier 5
Pier 6
Pier 7
Pier 8
Abut. 9
39+40
40+40
41+40
42+40
43+40
44+40
45+40
Station (ft.)
"12/29/52"
"9/17/87"
"2/14/2001"

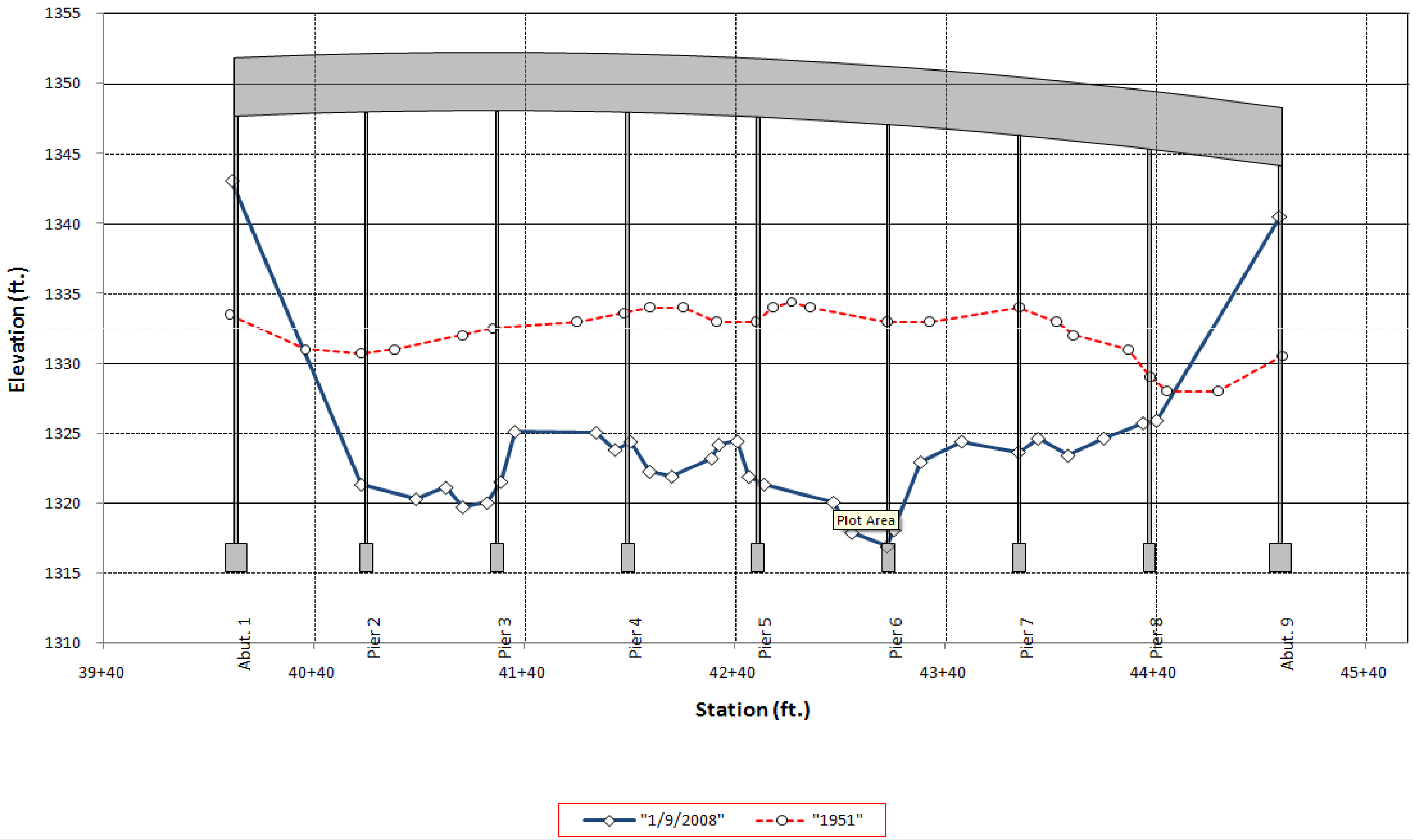


Bridge ID: 56-0004R
08-RIV-010-27.69
Whitewater River - Upstream Side
Looking Upstream
To Indio
Elevation (ft.)
1360
1350
1340
1330
1320
1310
1300
Abut. 1
Pier 2
Pier 3
Pier 4
Pier 5
Pier 6
Pier 7
Pier 8
Abut. 9
39+40
40+40
41+40
42+40
43+40
44+40
45+40
Station (ft.)
"12/29/52"
"9/17/87"
"2/14/2001"
"1/9/2008"

Bridge ID: 56-0004R

Whitewater River - Downstream

08-RIV-010-27.69

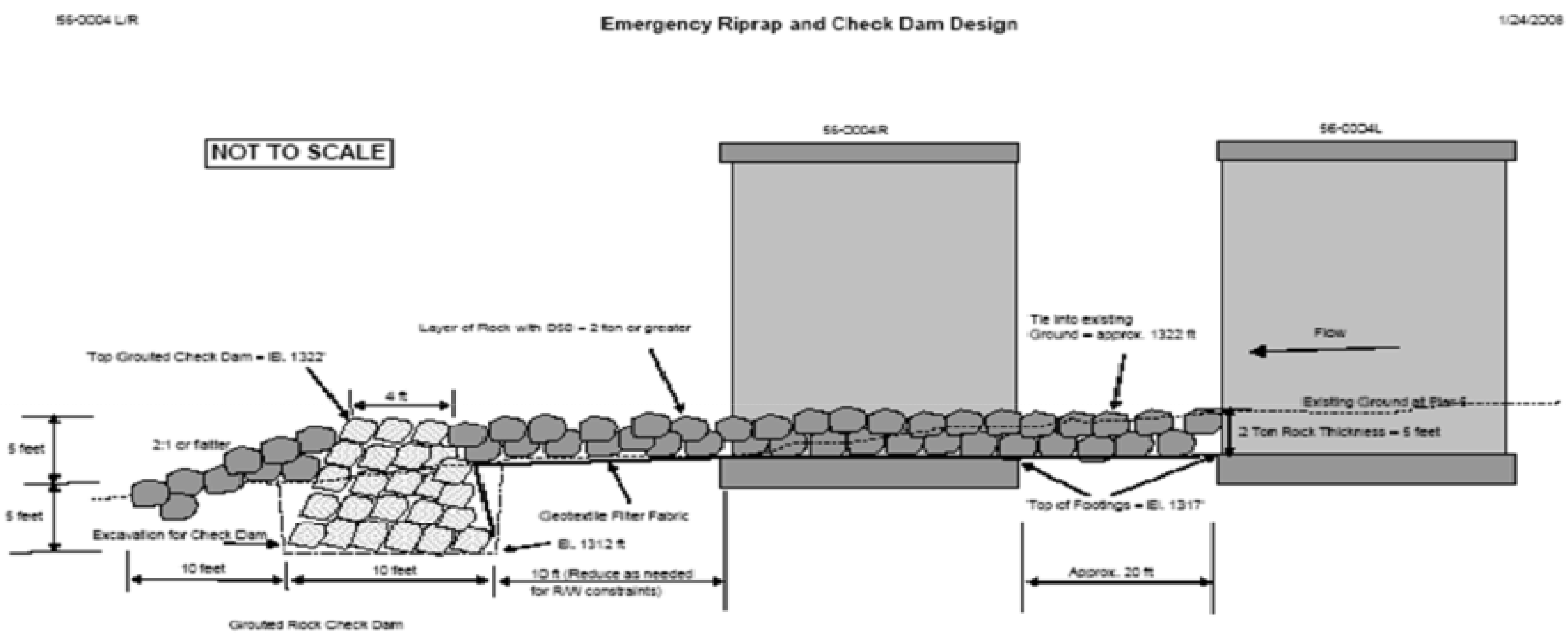


Only 6 inches of cover over the top of the Spreadfooting

Scour Analysis Results

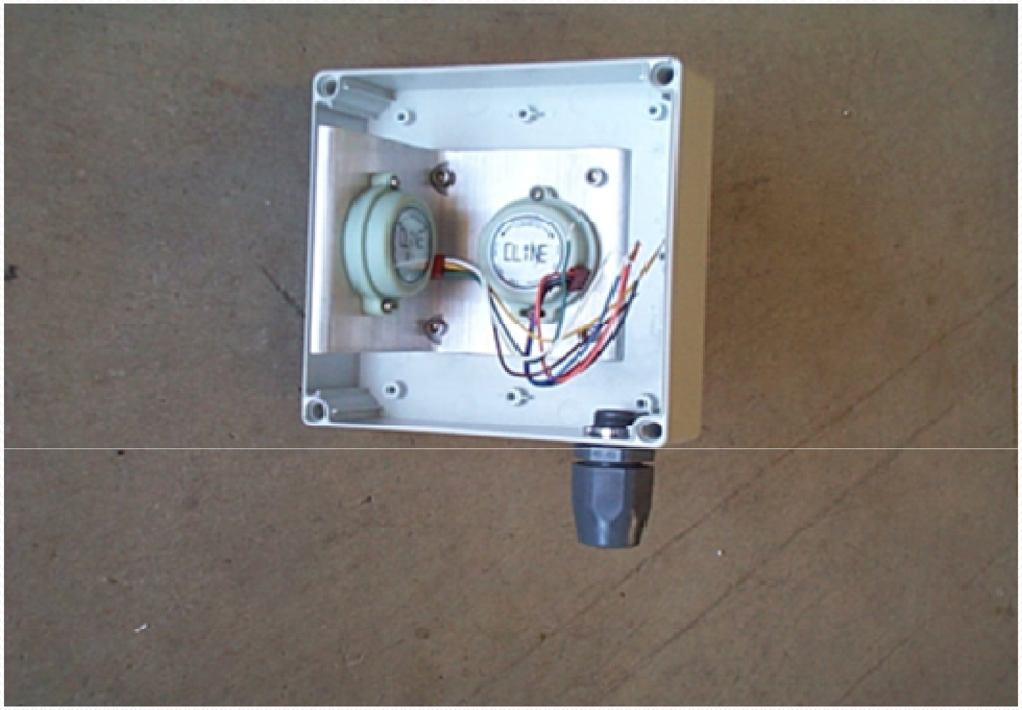
- Bridge was determined to be Scour Critical
- More than 25% of the spreadfooting would be undermined by a 2-Year Flood event
- The bridge would likely fail catastrophically
- ➔ Since Route is an Interstate with ADT = 30,000 and is critical link for Palm Springs, this was an EMERGENCY!

Proposed Emergency Countermeasures



Grouted Rock Checkdam with Riprap protection around the Piers

MONITORING INSTRUMENTATION

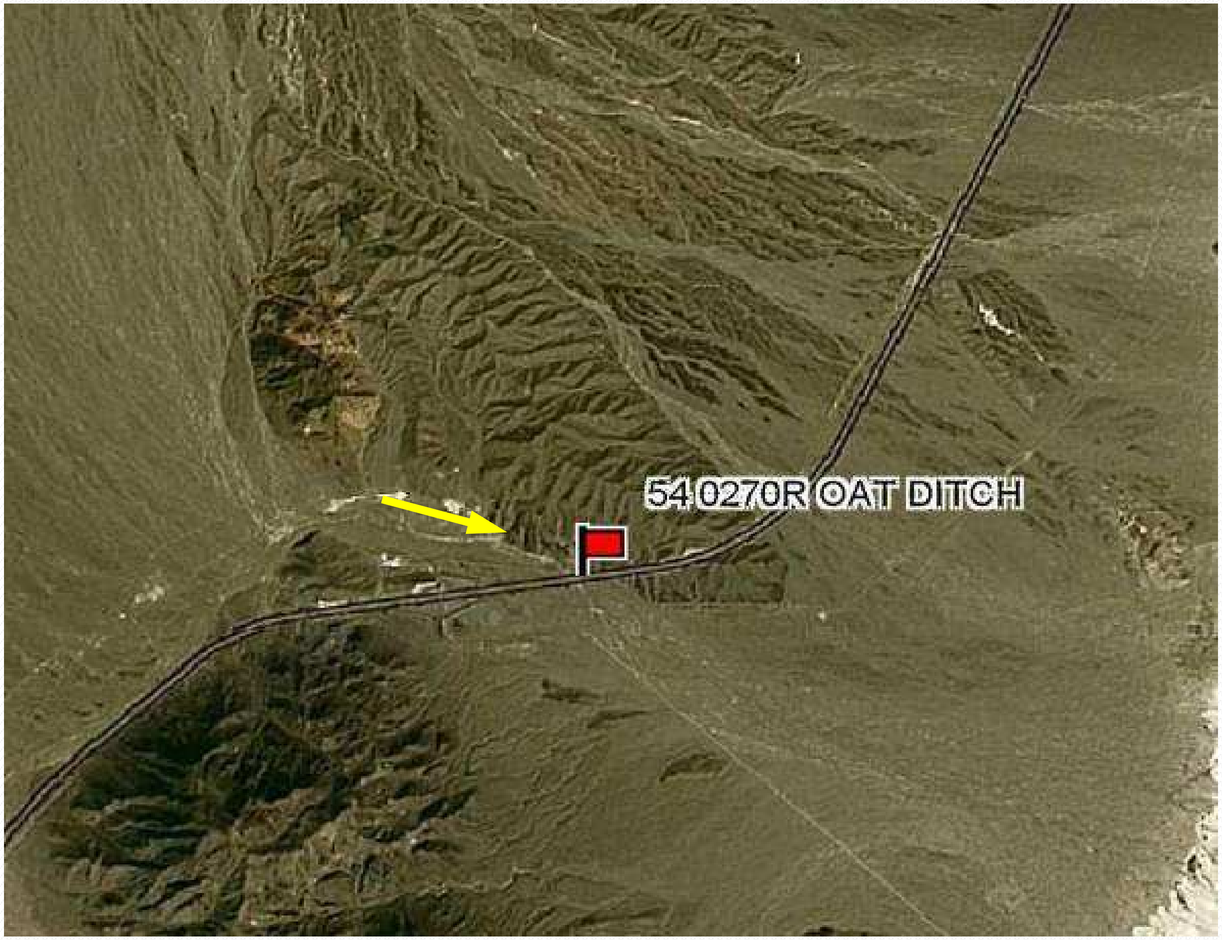


TILT SENSOR

Monitoring Cross-Sections isn't always enough

- Monitoring during floods is very difficult
    - Requires instrumentation
    - Manpower
    - Notification
- After the flood recedes, scour often refills
- Accurate scour prediction is necessary
- Looking beyond the limits of the bridge is essential

Br. No. 54-0270 at Oat Ditch on I-15 in San Bernadino County

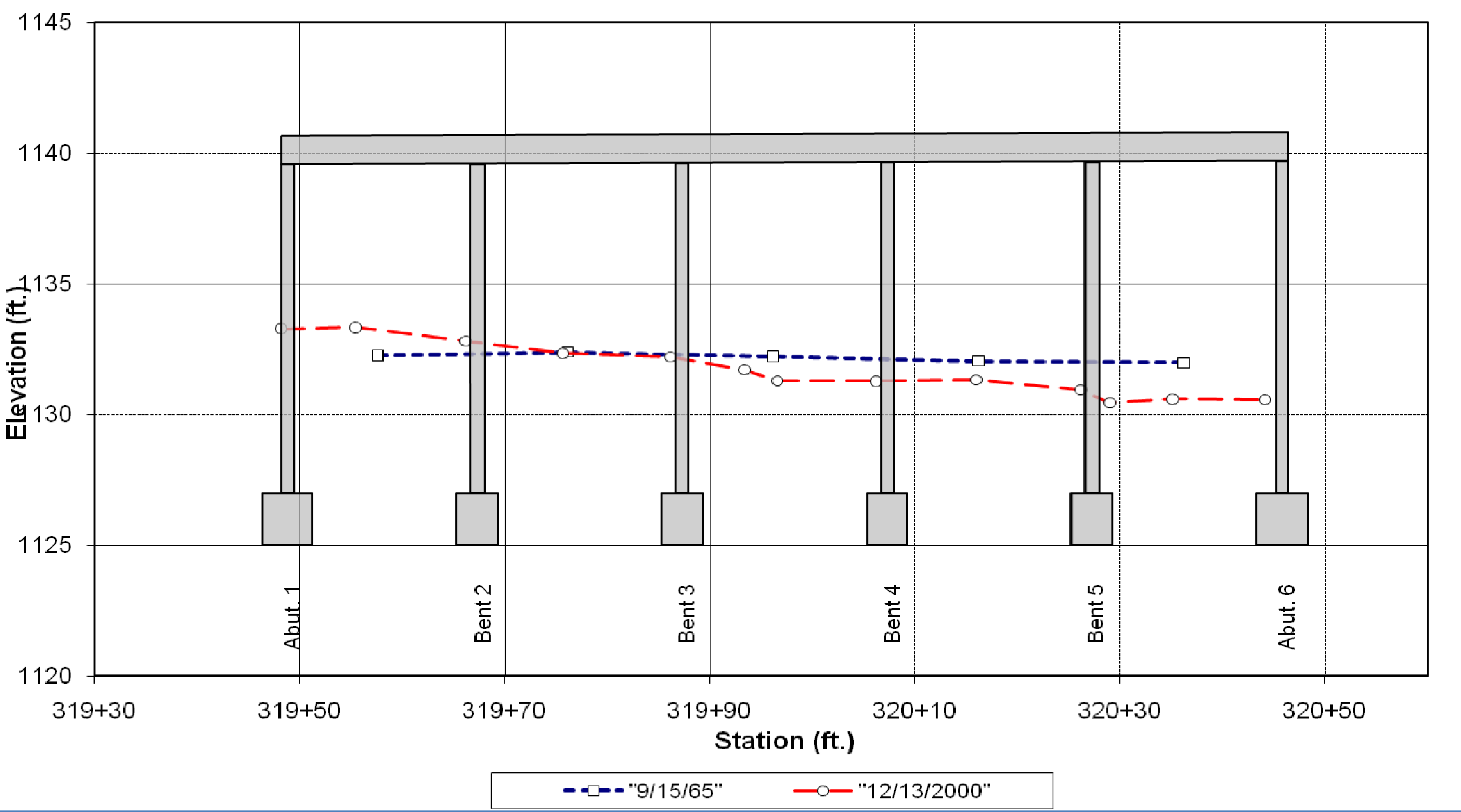


Bridge creates a contraction and is located at a bend in the channel

Bridge ID: 54-0270R

08-SBD-015-R130.59

Oat Ditch Bridge - Upstream



Initial Scour Evalution

•Stable Cross-Sections over 35 years

•Potential Pier Scour was above the Top of Spreadfooting

Bridge was coded in 2001 as NOT SCOUR CRITICAL

Flash Flood Event

•Late evening 08/19/03 & early morning hours on 08/20/03, 2 inches of rain poured down on the Oat Ditch basin in approx. 40 minutes by some estimates

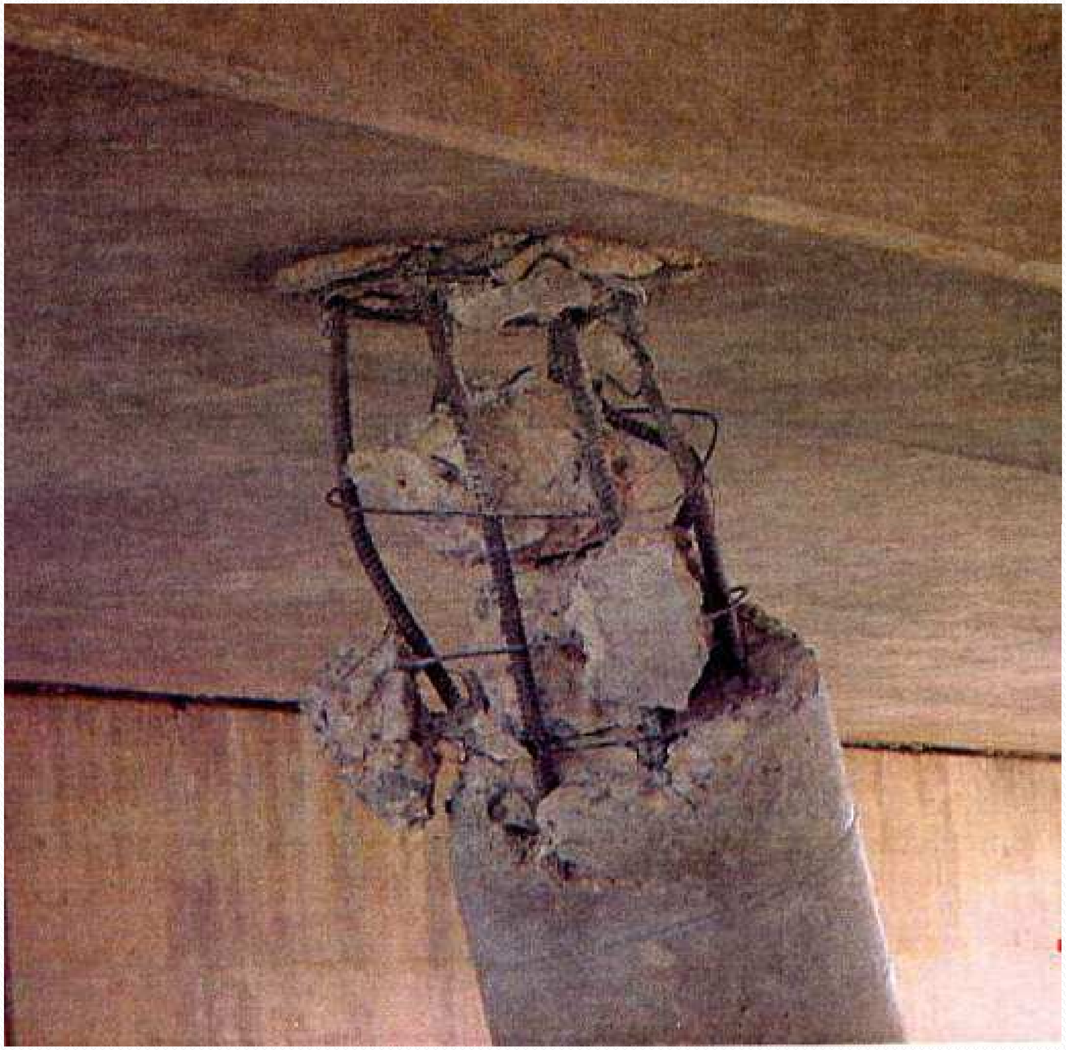
•Bent 5 – Right Bridge, columns 1 thru 3 failed at bent cap joint

First Signs of Failure

•

Damaged Bents

Column Failure



Column 2 bent cap joint failure - typical

Oat Ditch Repairs

New Columns at Bent 5 of the Right Bridge

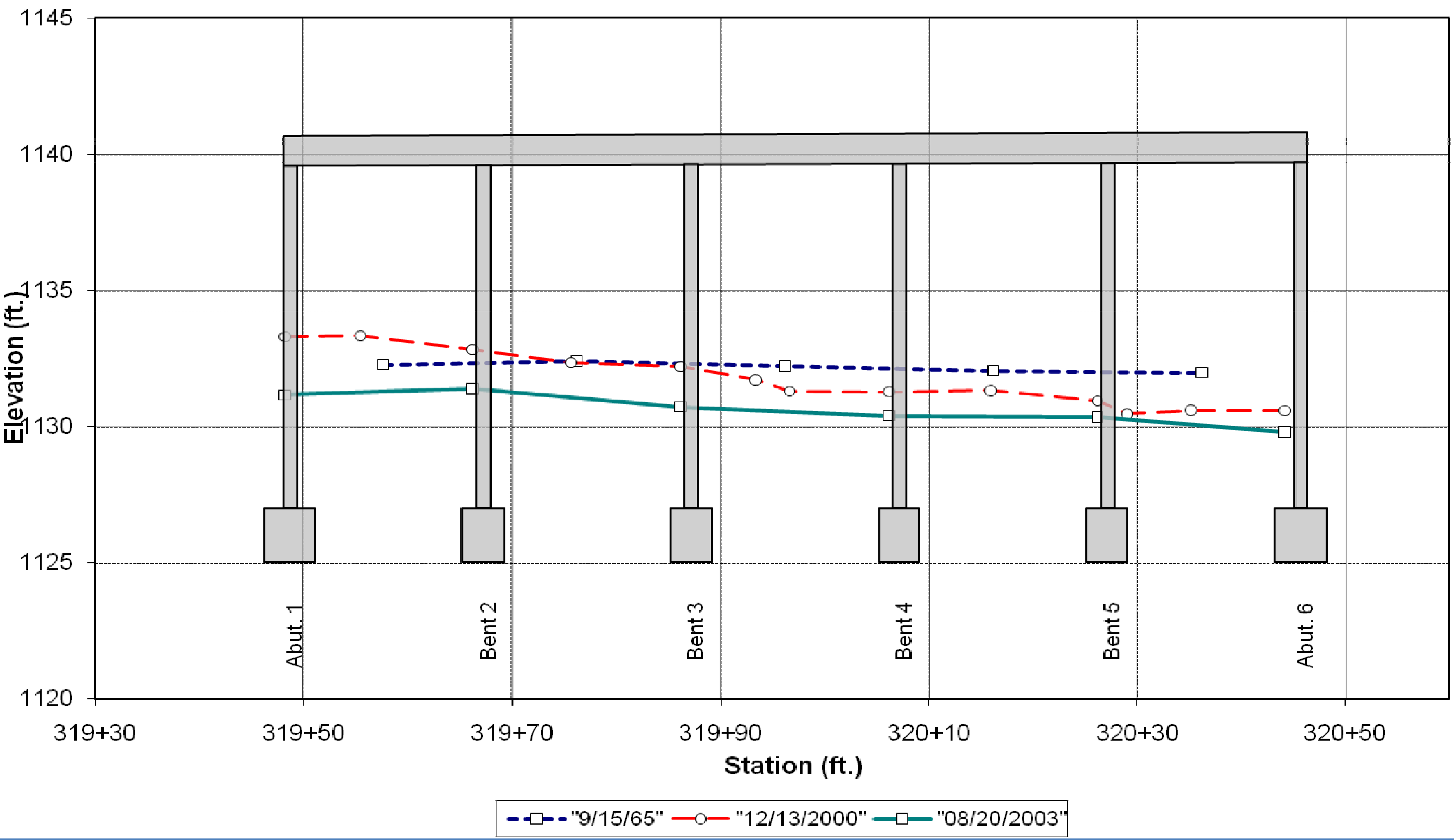
Oat Ditch Repairs

Scour Slab under both structures

Bridge ID: 54-0270R

08-SBD-015-R130.59

Oat Ditch Bridge - Upstream



So What Went Wrong?

- Scour Predictions were not conservative due to the flash flood nature of the dessert wash

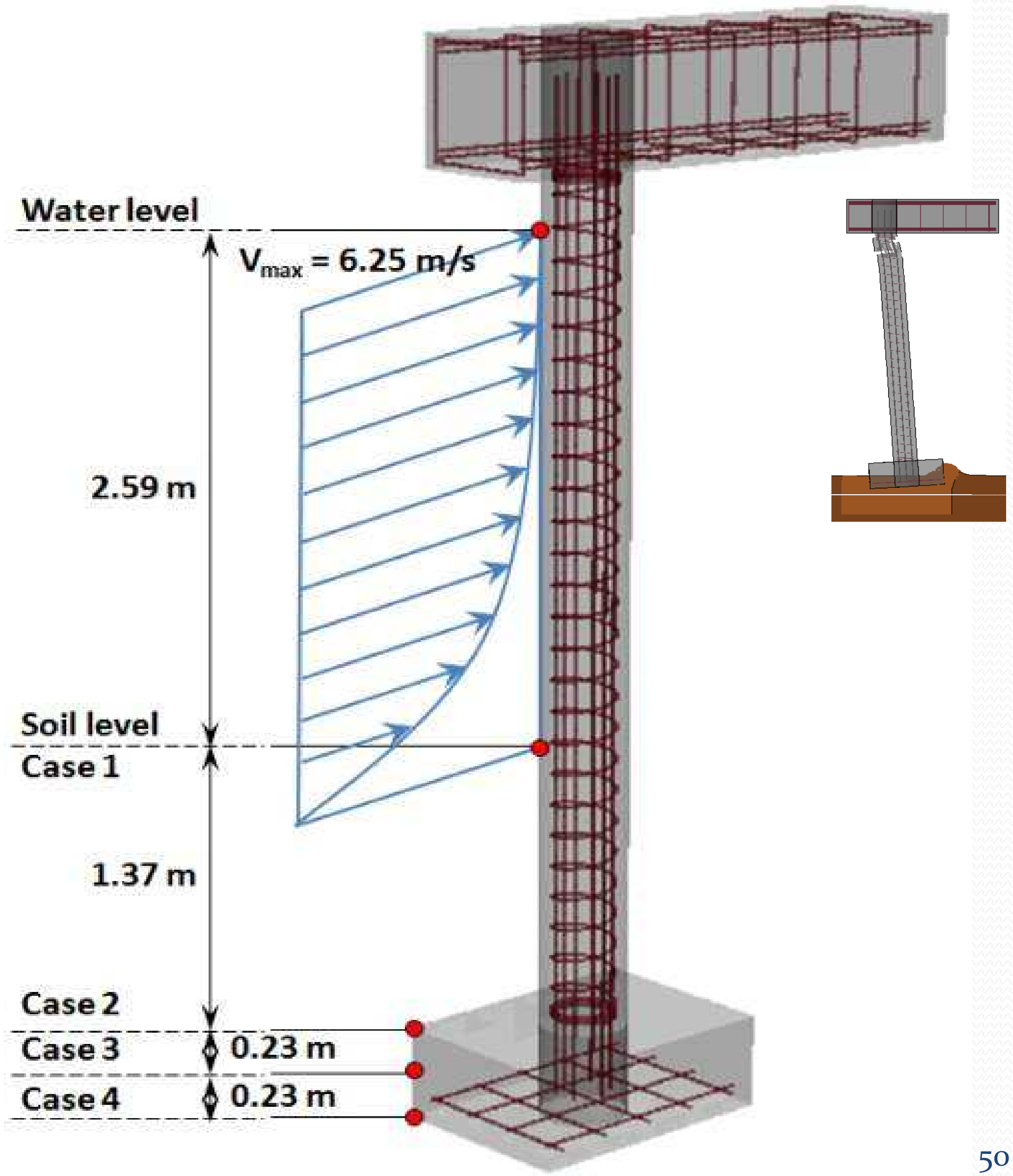
    - Channel is located at a bend in the wash

    - Channel creates a contracted Opening

- Possibly the Soil may have Fluidized

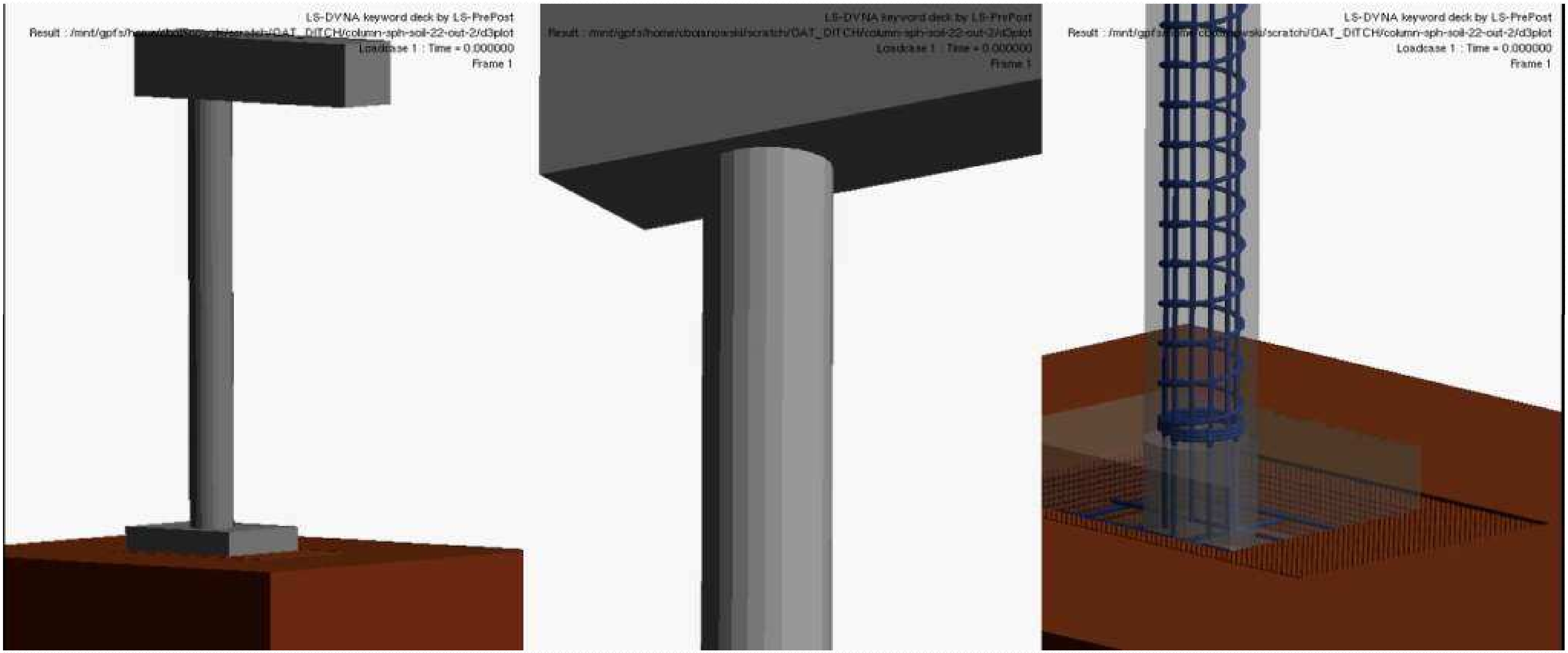
Fluid-Soil-Structure Interaction Approach

The Oat Ditch Bridge on I15 in California failed from hydraulic loading on support piers during a flood in 2003. Large deformation soil-structural interaction failure analysis was able to capture the failure mode.



Dr. Bojanowski and Dr. Kulak,
Argonne National Laboratory

FSSI Simulation Shows Oat Ditch Bridge Failure Mode



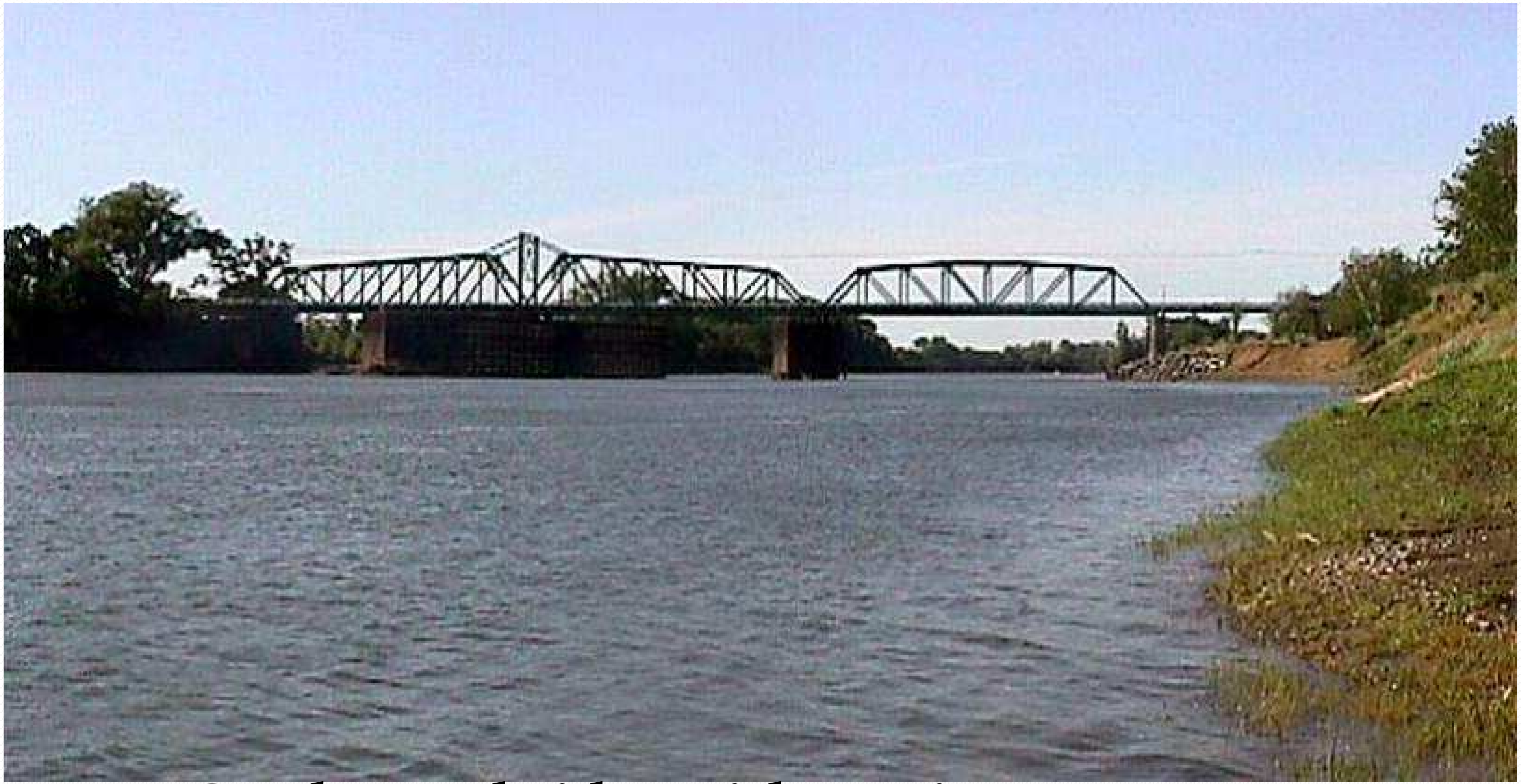
Beyond Cross-Sections…

How to Improve on our Monitoring and Scour Prediction

- Look beyond the bridge → Bathymetric Surveys
  → Aerial Photography
- Improve the Hydraulics Calculations → 2-D Modeling

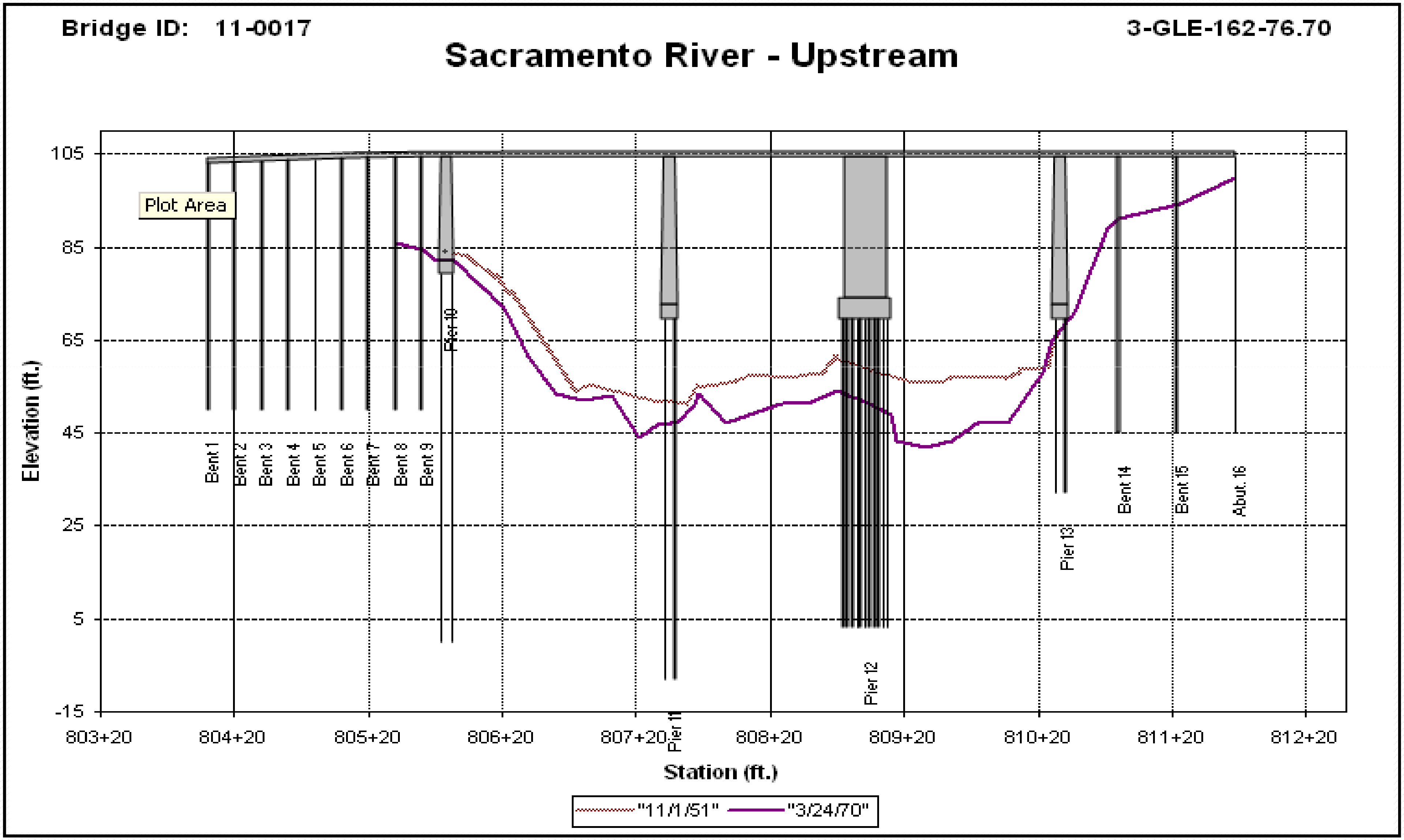
- LONG TERM GOAL: Improve our Scour Analysis
  → Model the physics of the flow and scour using 3-D models

When cross-sections are not enough…
A case for a bathymetric survey
Bridge No. 11-0017 – Sacramento River

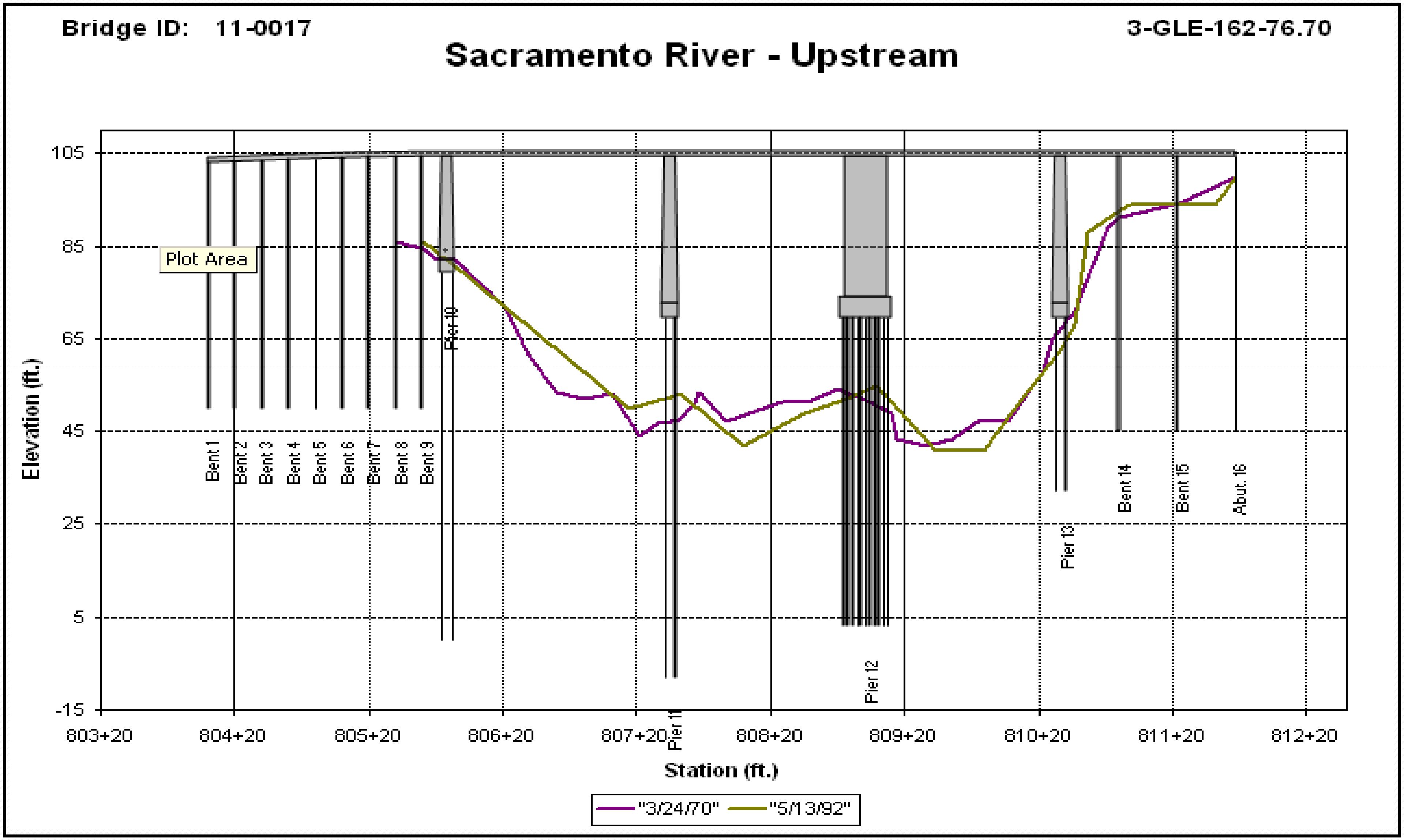


Steel truss bridge with a swing span

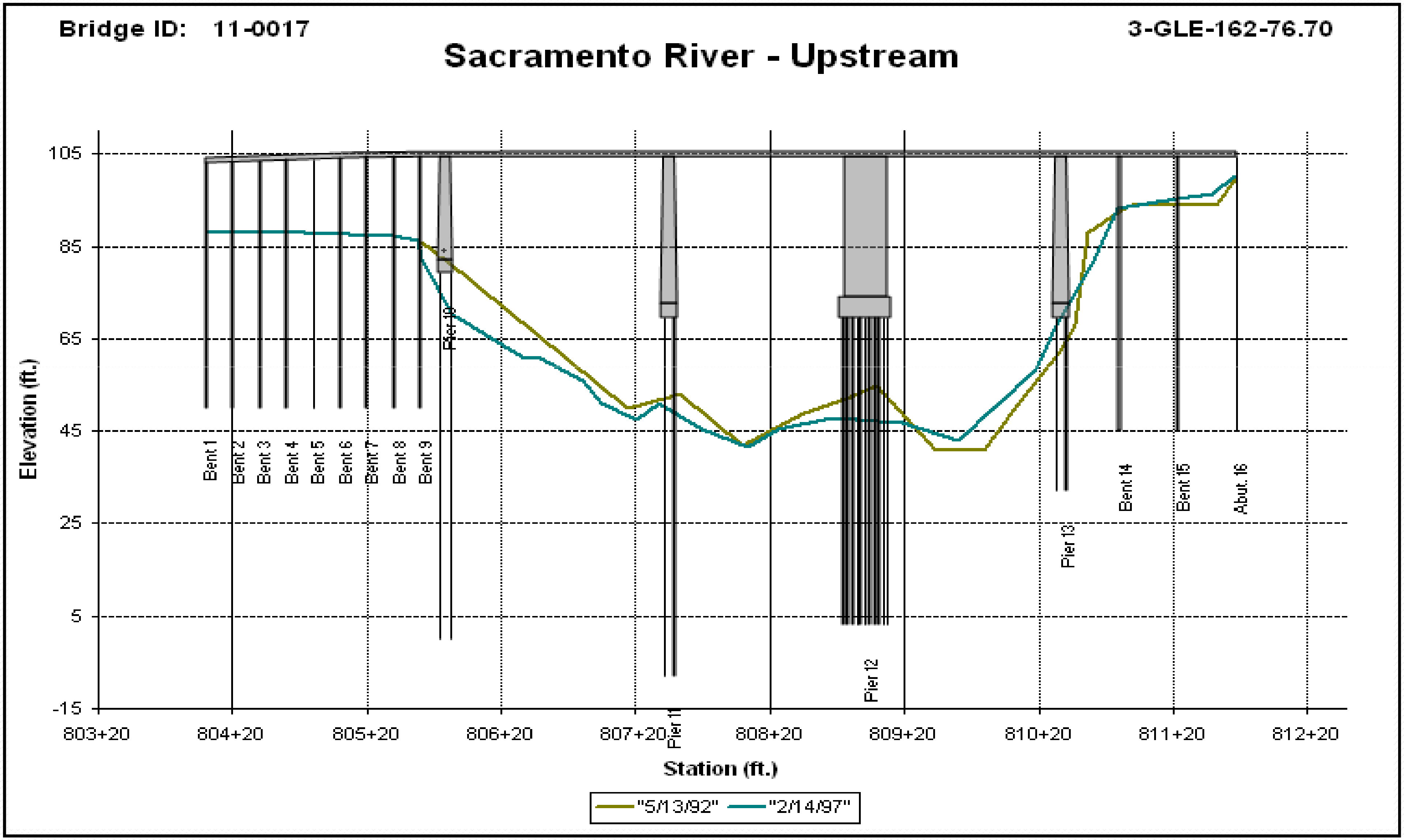
Historic Channel Changes



Historic Channel Changes

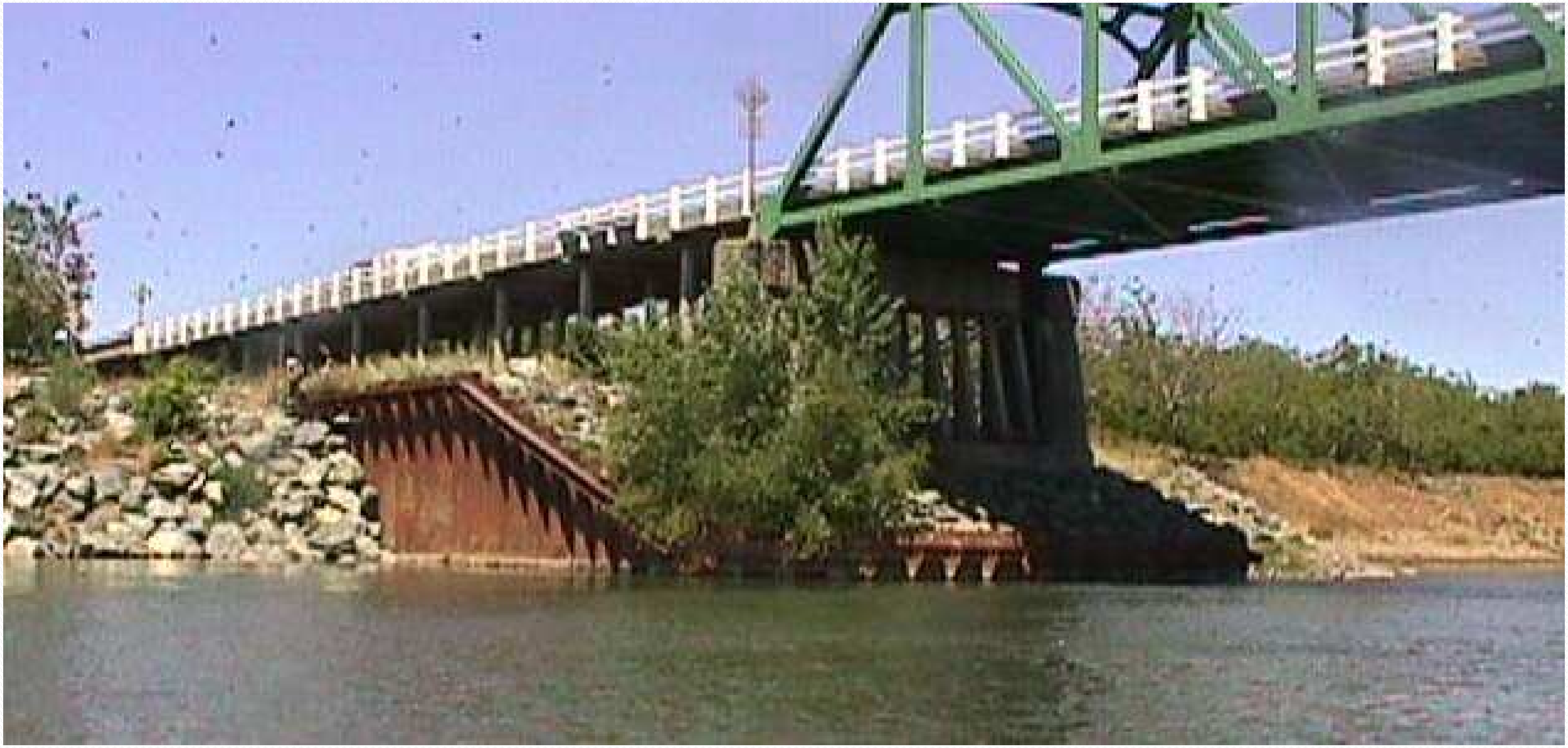


Historic Channel Changes



1997 Bank Erosion

Sheetpile Countermeasure - Dec. 1997



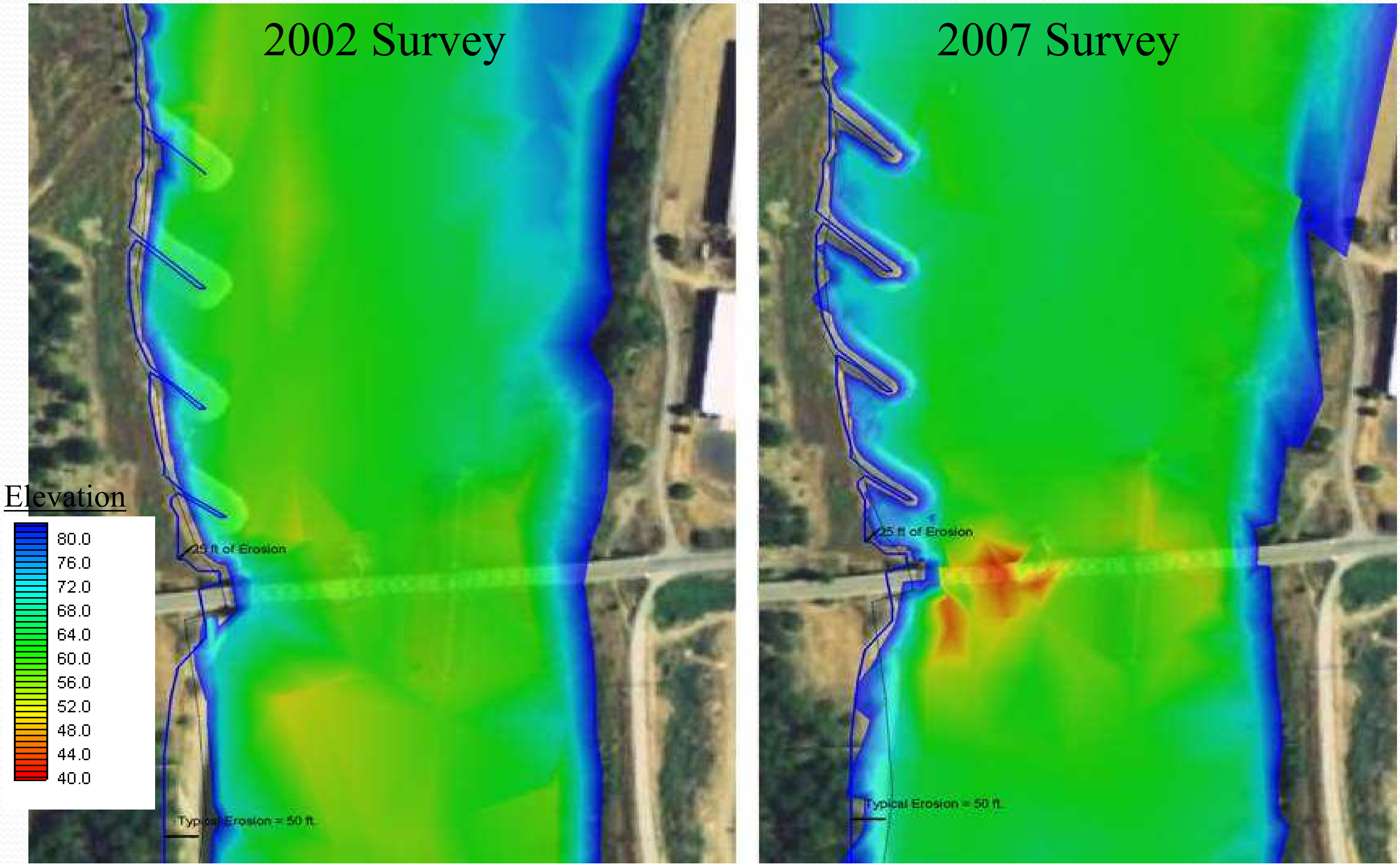
Bank Continued to Erode

Construction of the Spurs

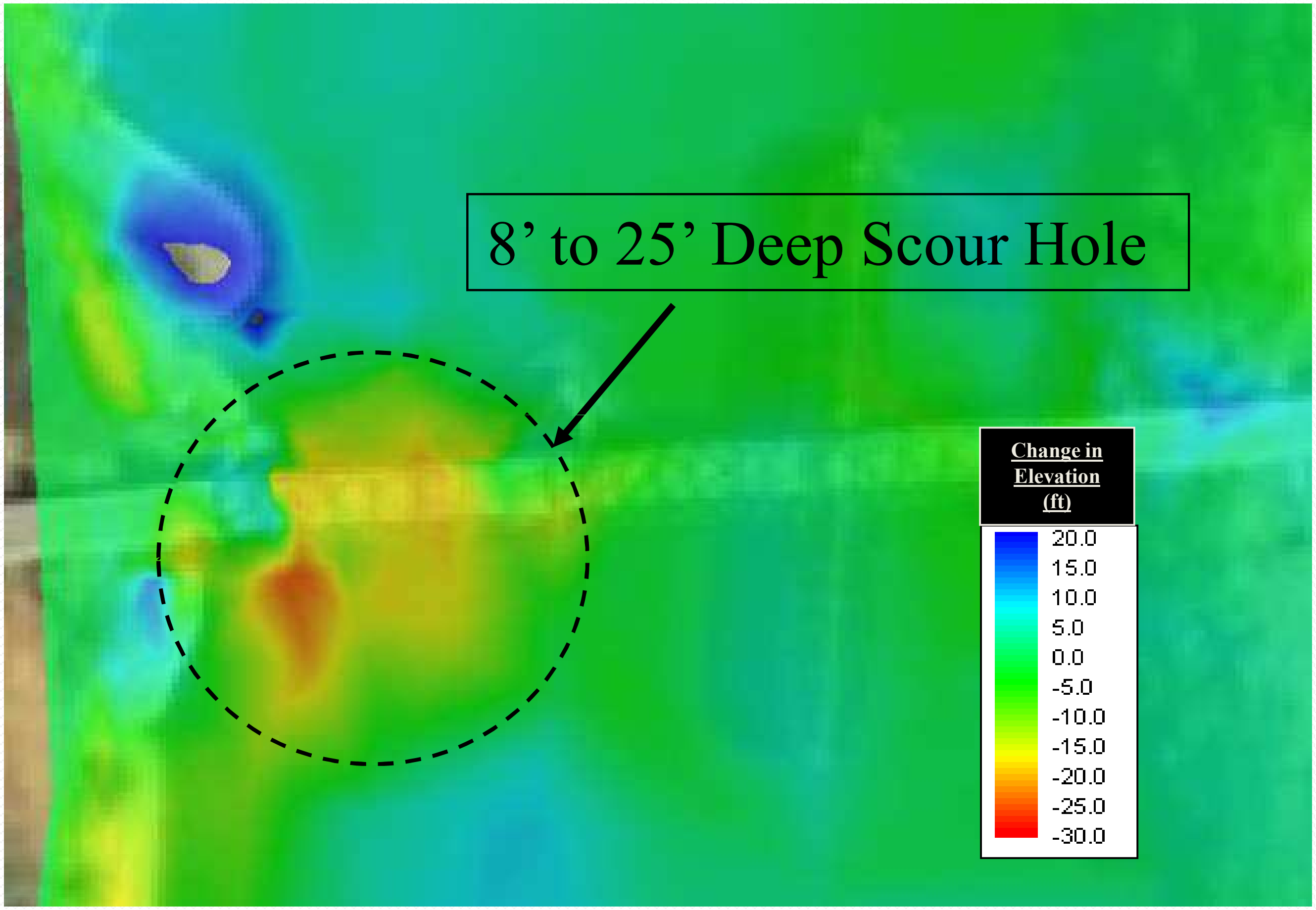

Flow
Butte City
Route 162

Spurs Built in 2004

Survey Comparison



Unexpected Scour



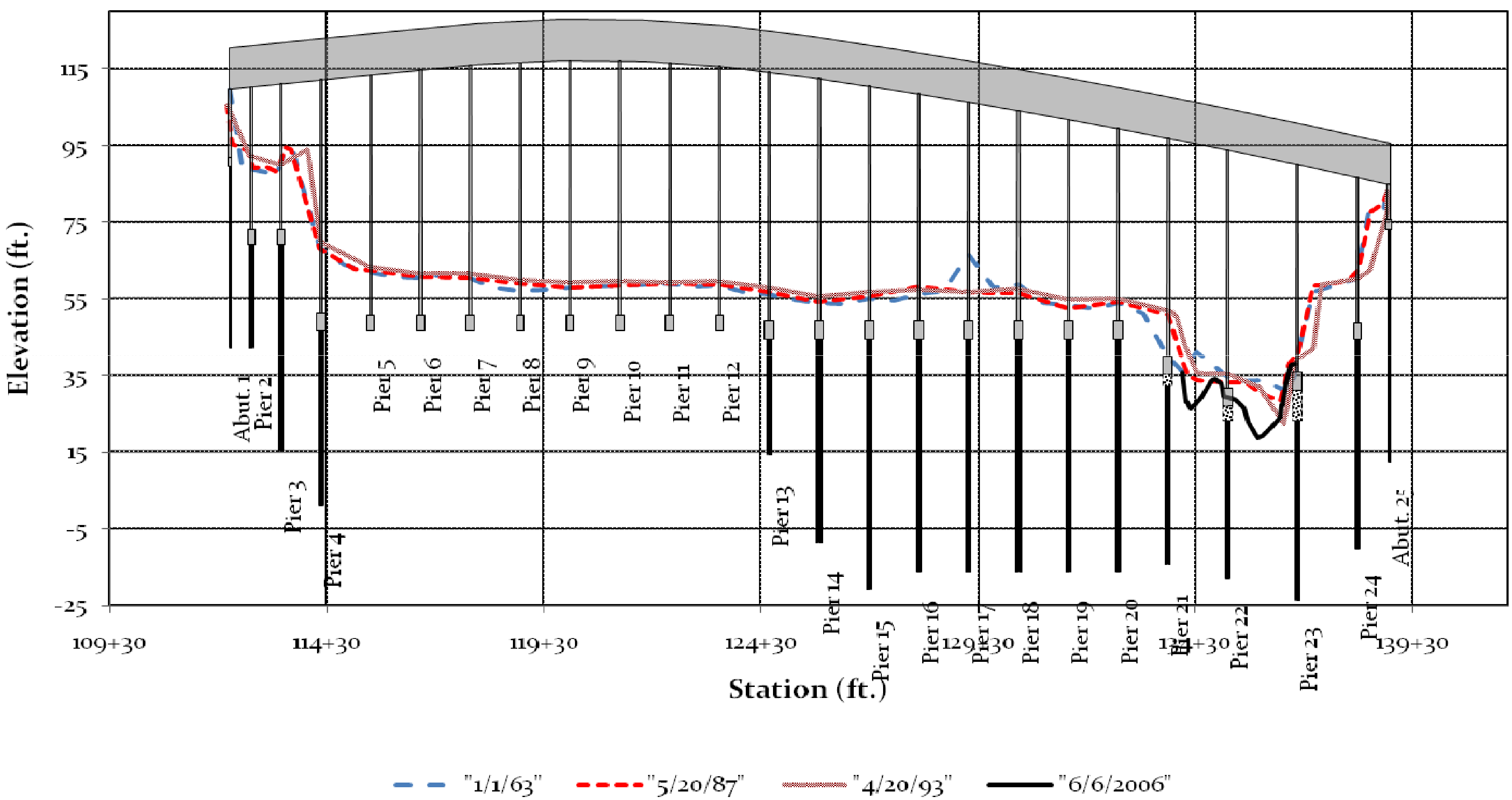
Bridge is currently being analyzed for potential instability of the main channel piers

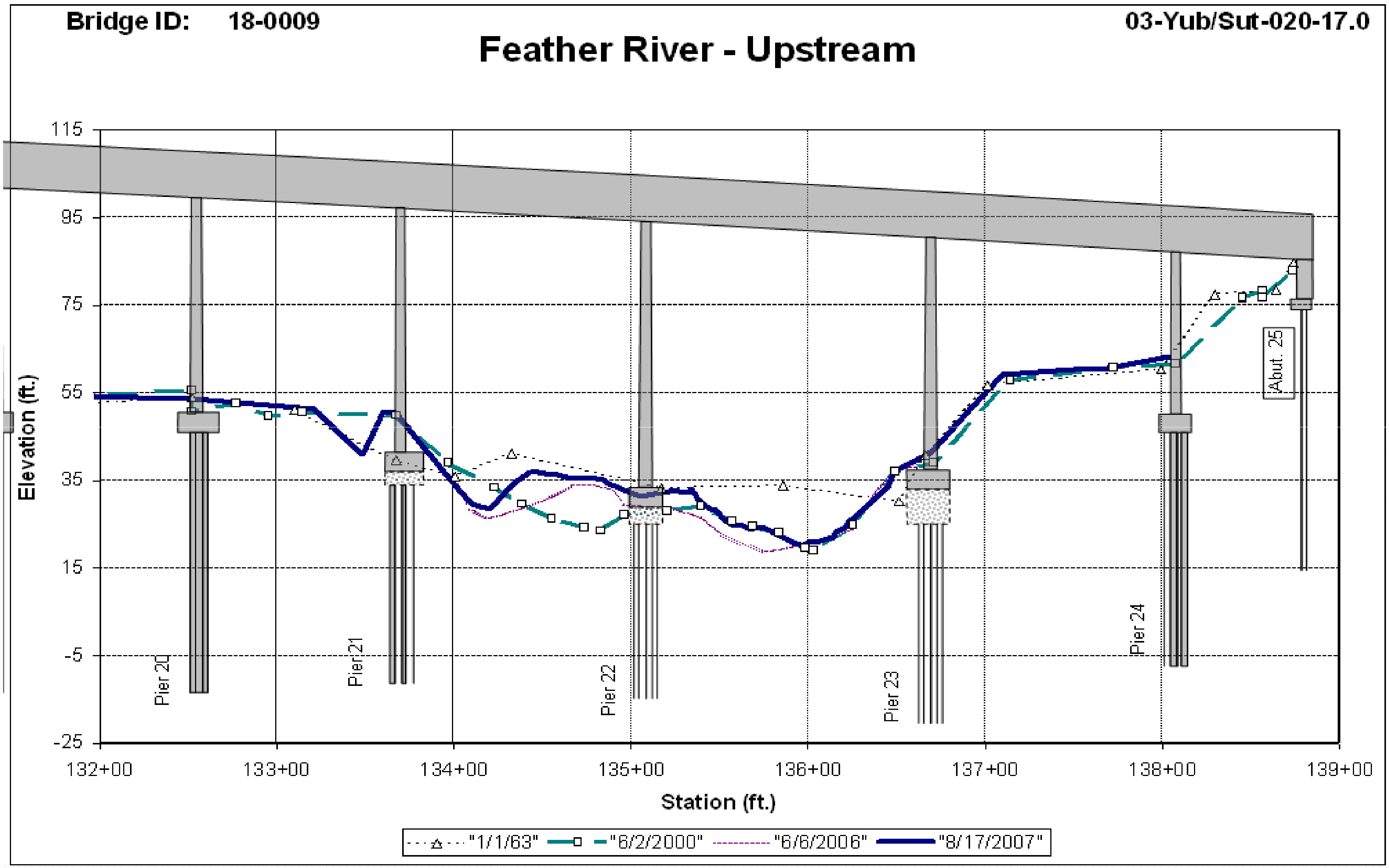
When cross-sections are not enough…
A case for analyzing aerial photography
Bridge No. 18-0009 Feather River Bridge

Bridge ID: 18-0009

Feather River - Upstream

03-Yub/Sut-020-17.0





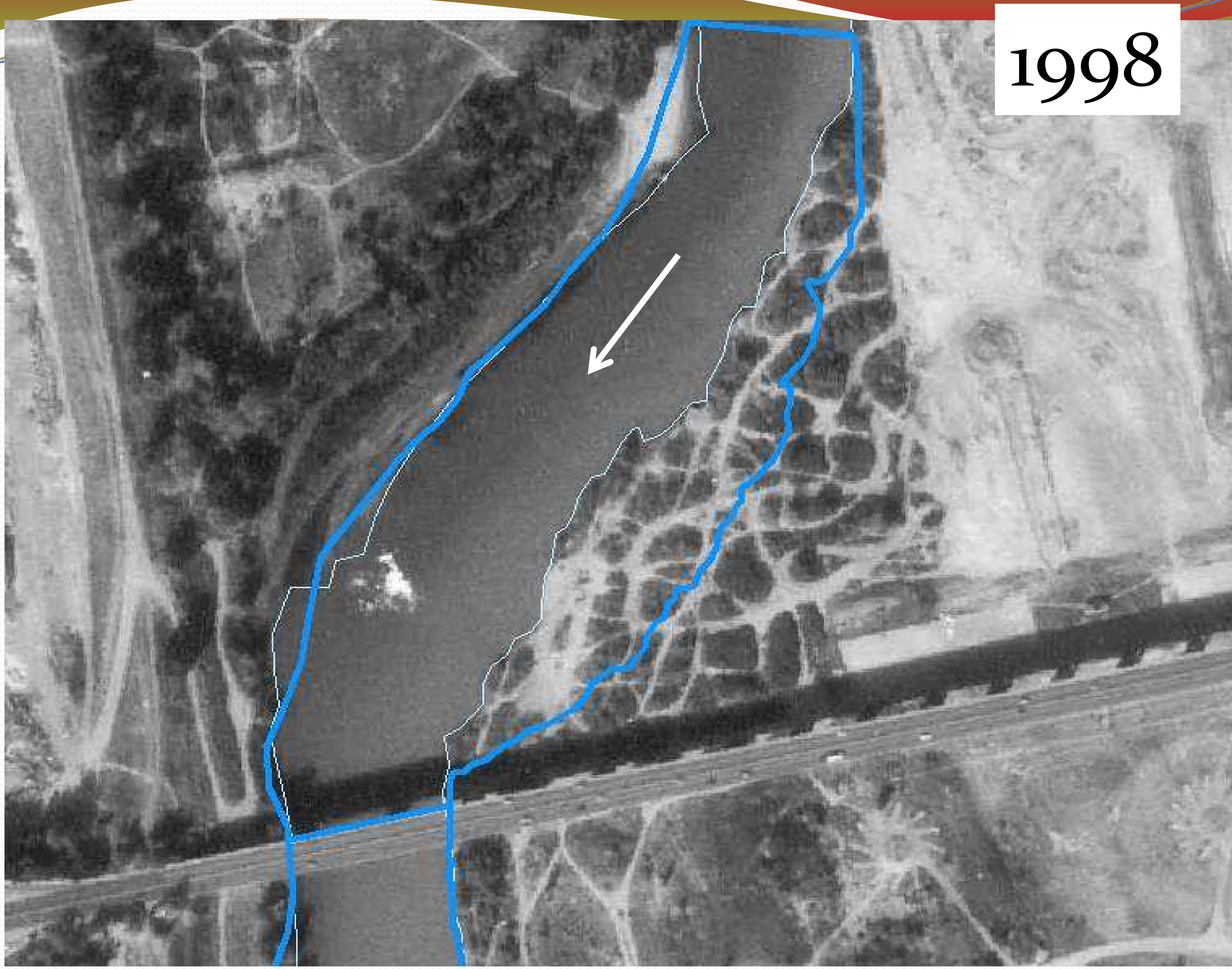
Cross-sections show the river has deepened in the main channel , but been laterally stable

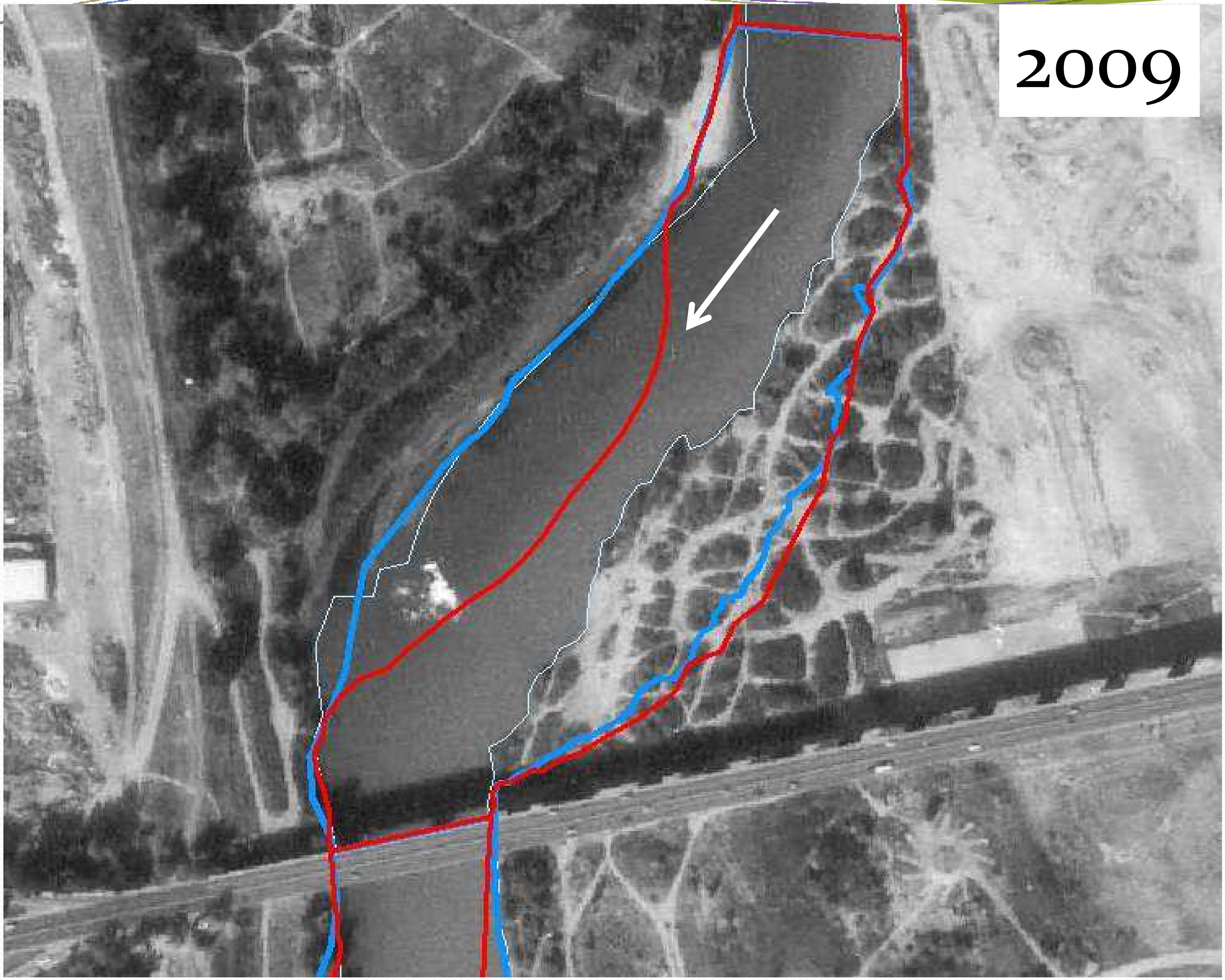
Mitigation Project

- Simple - Place large riprap around the 3 main channel piers

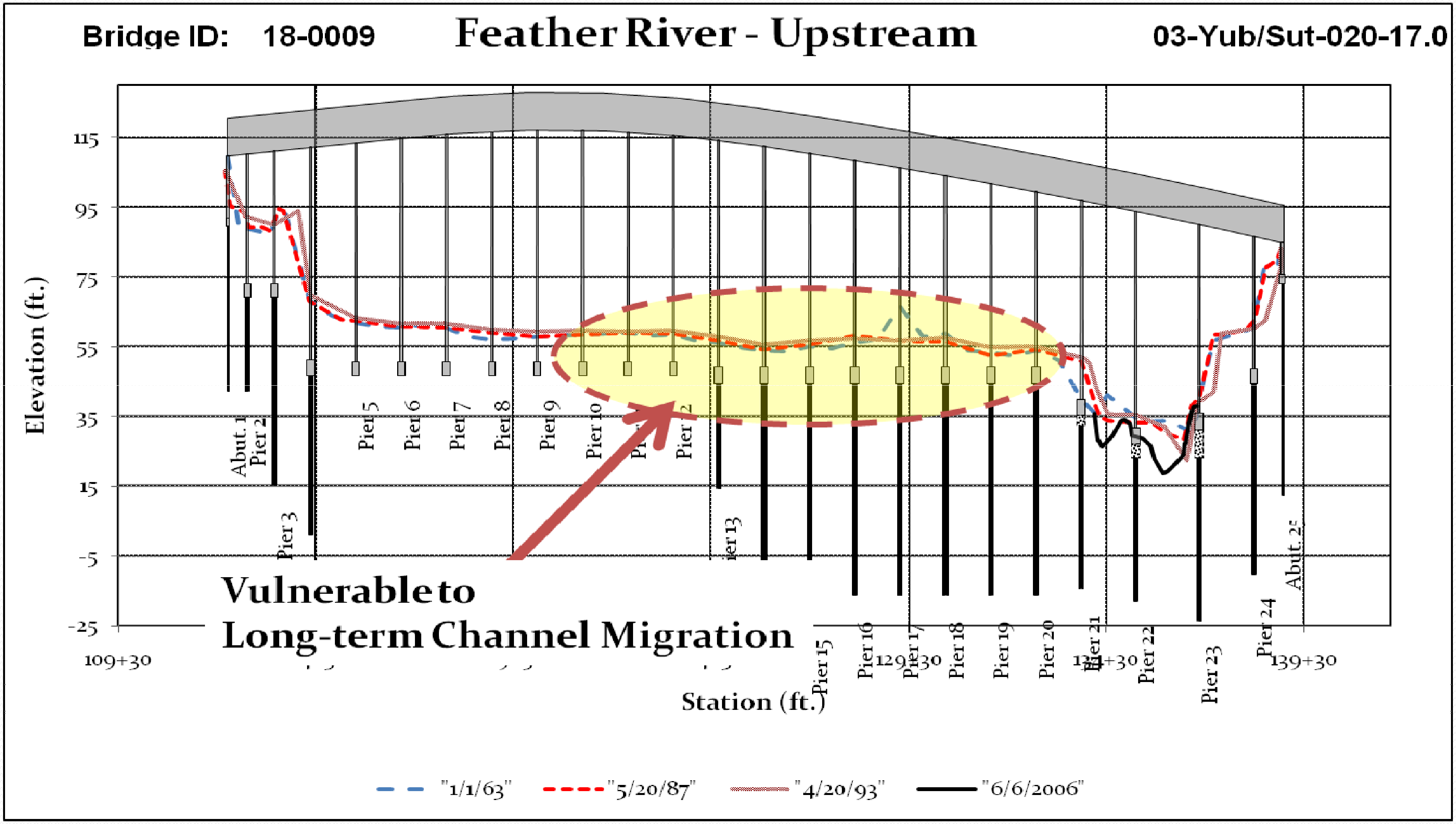
- What do the Aerial Photos Show?


1986


1998


2009

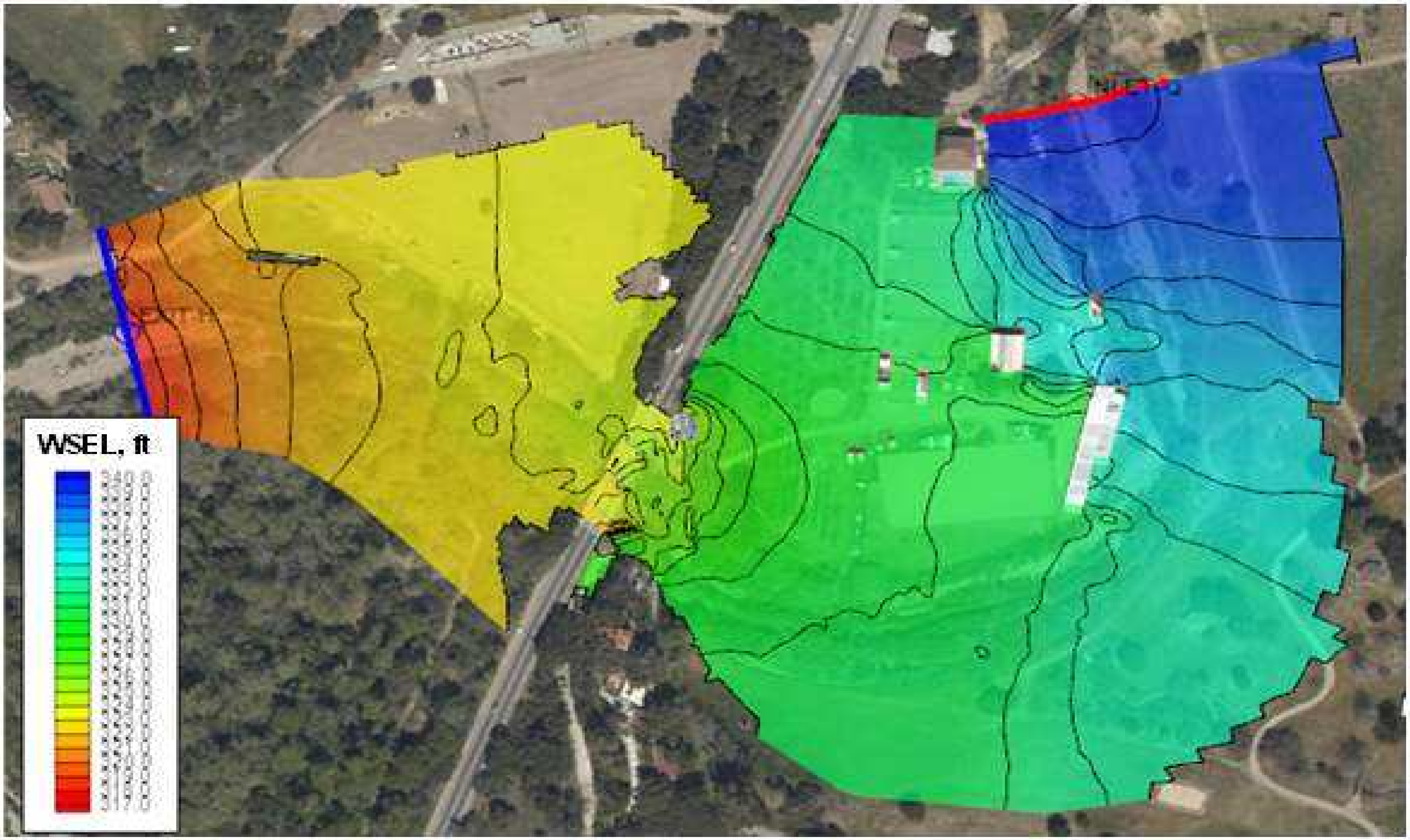

Bank Erosion from 1993 to 2009


Bridge ID: 18-0009
Feather River - Upstream
03-Yub/Sut-020-17.0
Elevation (ft.)
Station (ft.)
Vulnerable to
Long-term Channel Migration
"1/1/63"
"5/20/87"
"4/20/93"
"6/6/2006"

When cross-sections are not enough…

A case for a 2-Dimensional Hydraulic Model

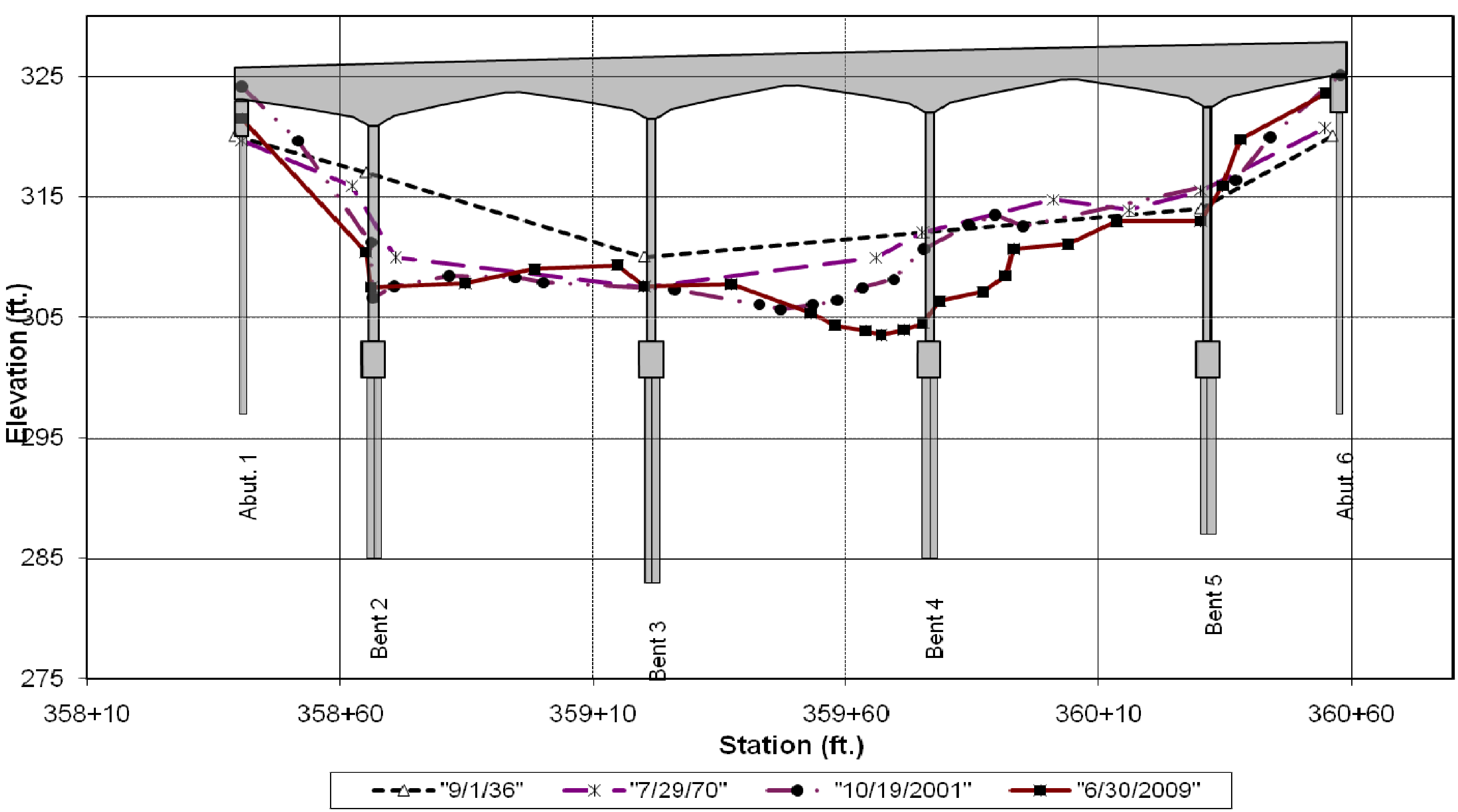
Bridge No. 52-0065 – San Antonio Creek



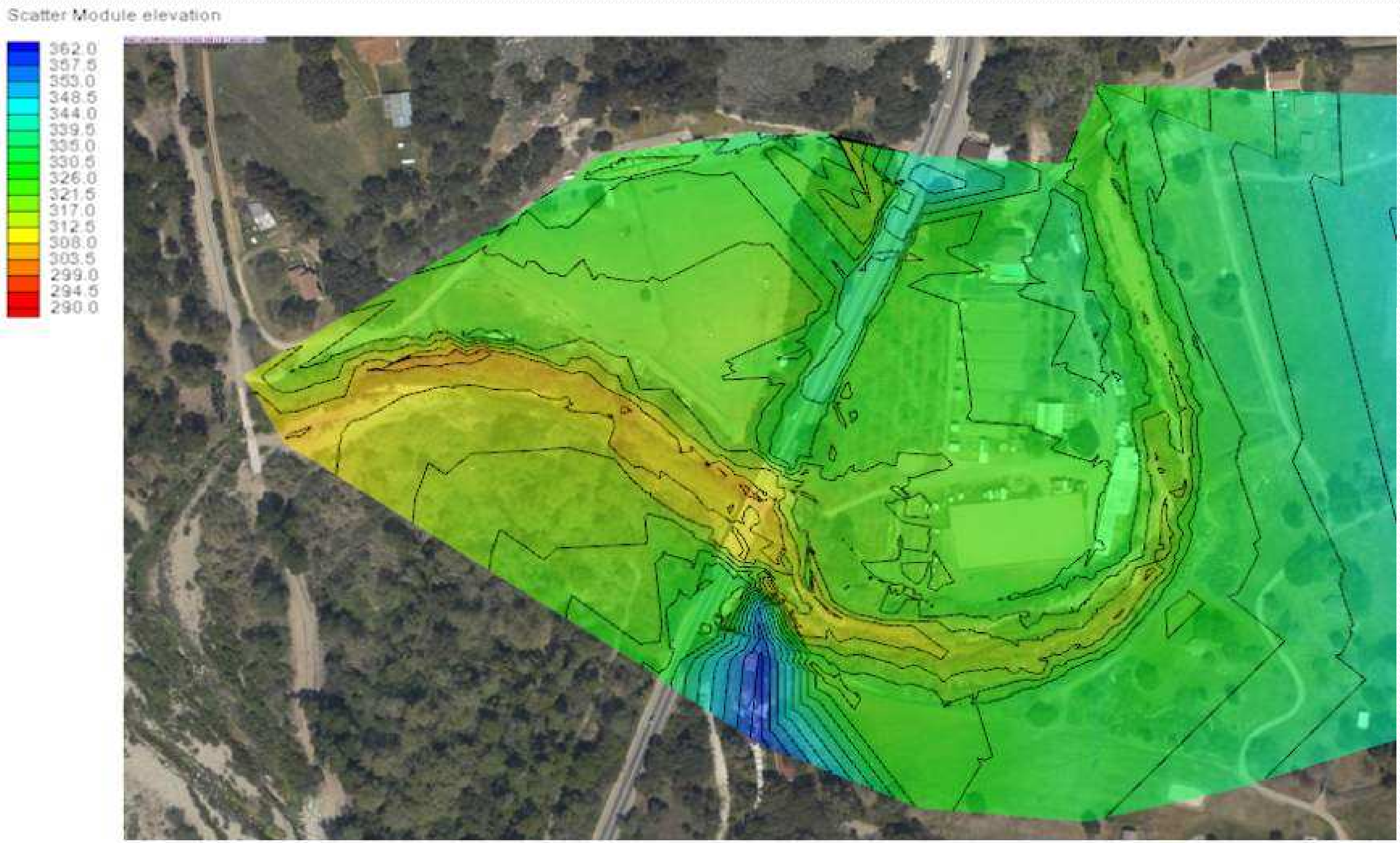
Bridge ID: 52-0065

San Antonio Creek - Upstream

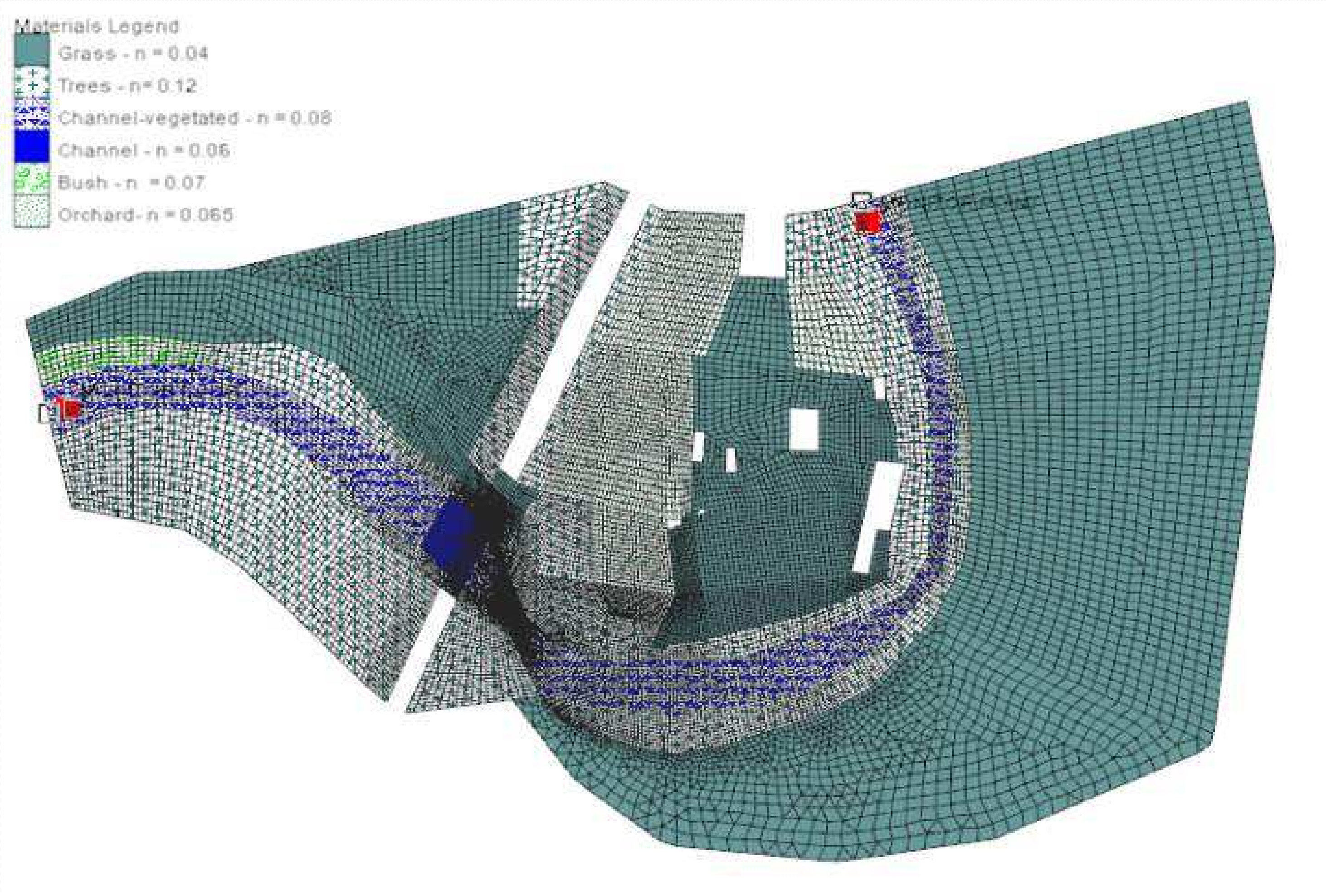
07-VEN-33-7.58



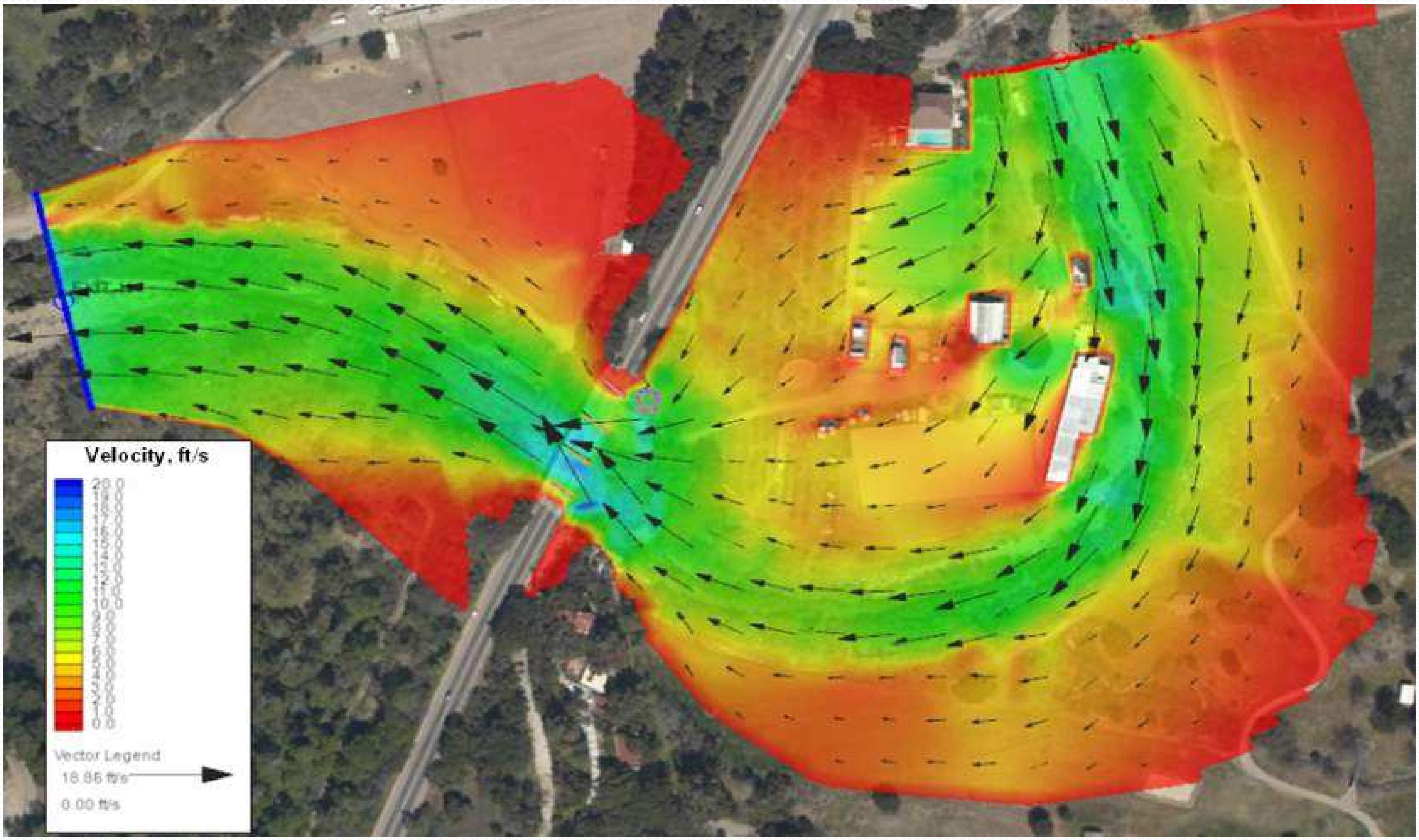
Topographic Survey



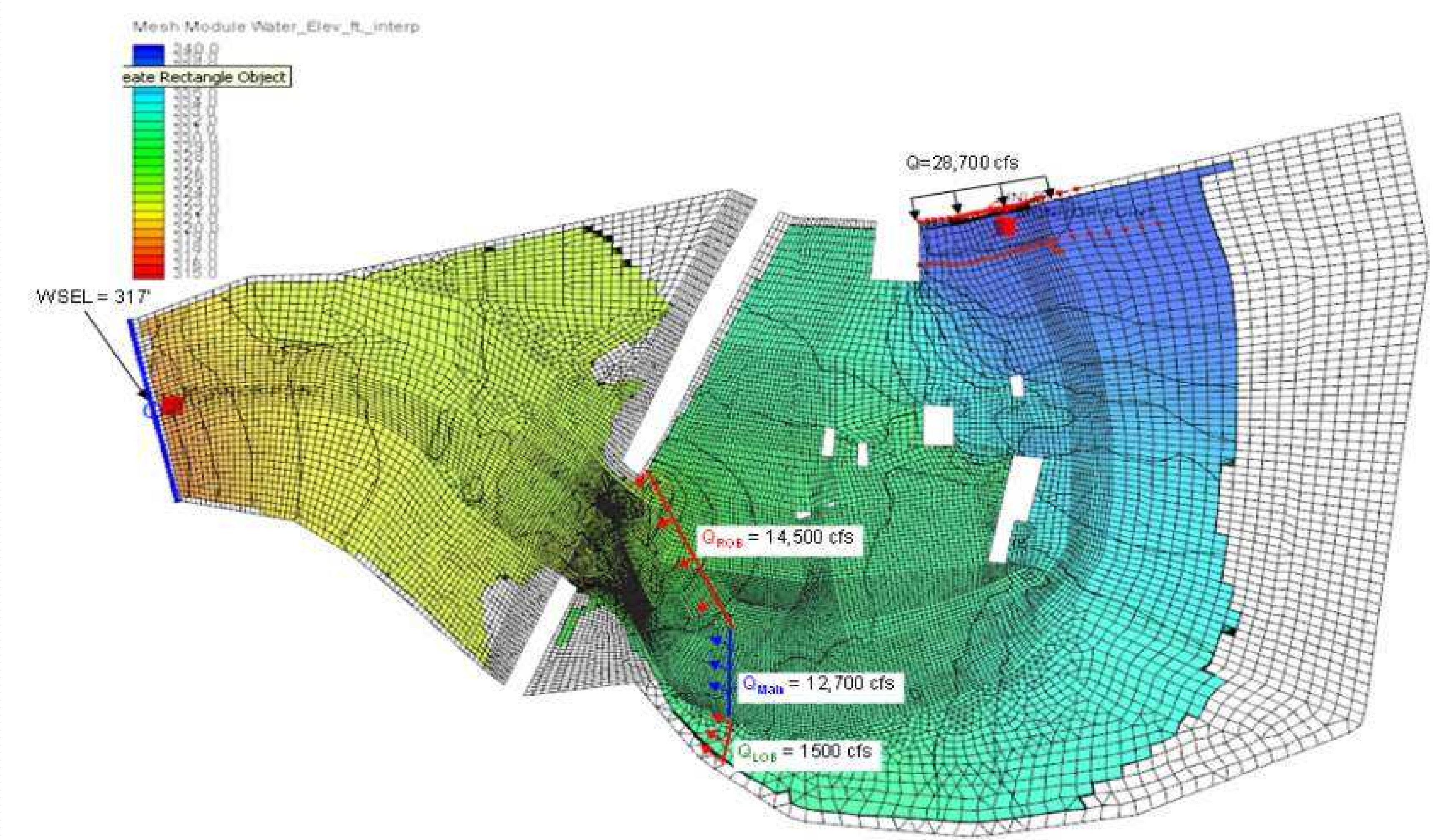
2-D Hydraulic Model
USBR's SRH-2D



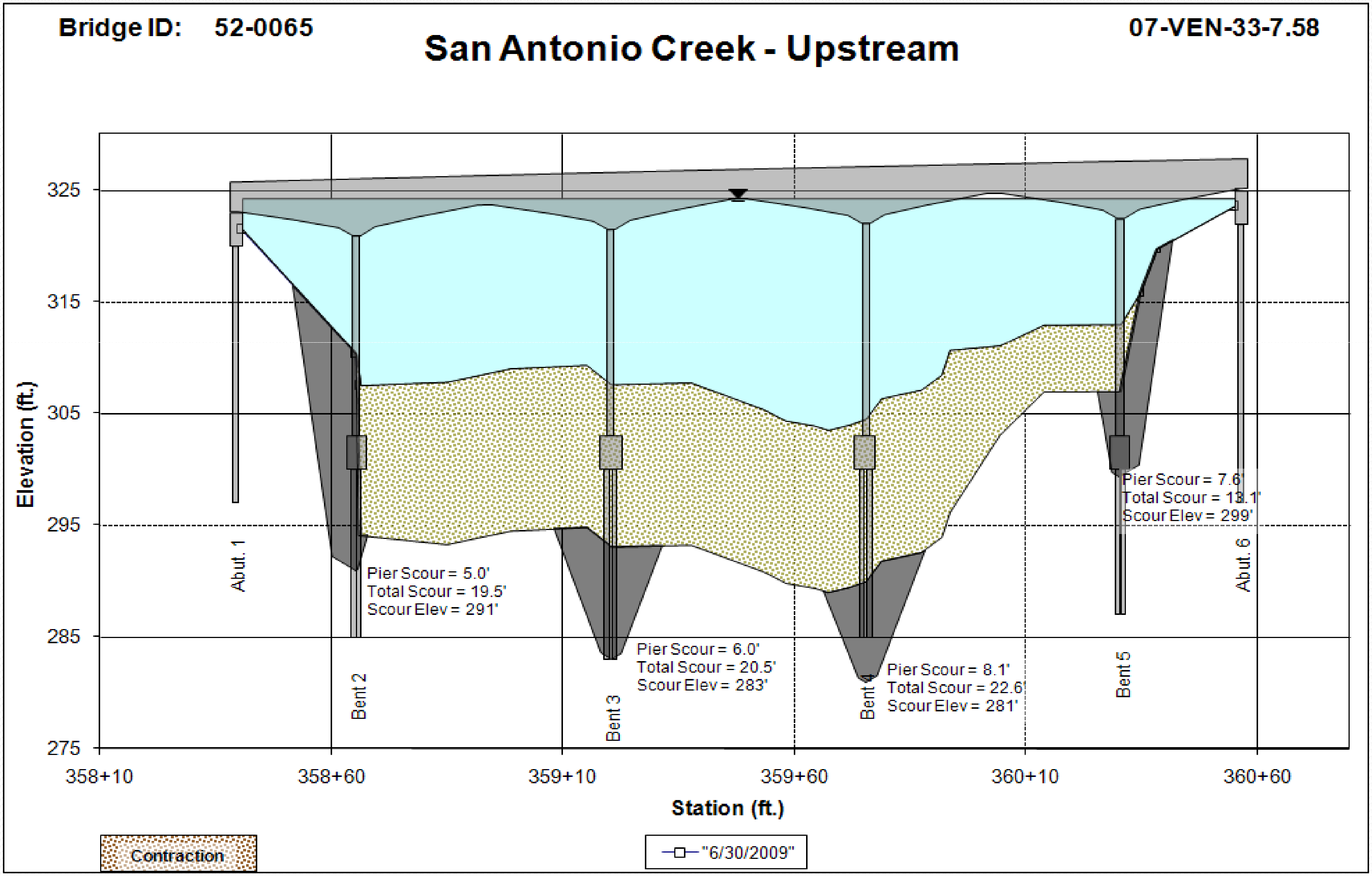
Velocity Distribution and Directions



More than 50% of Flow is in the floodplain
➔ 12 feet of Contraction Scour



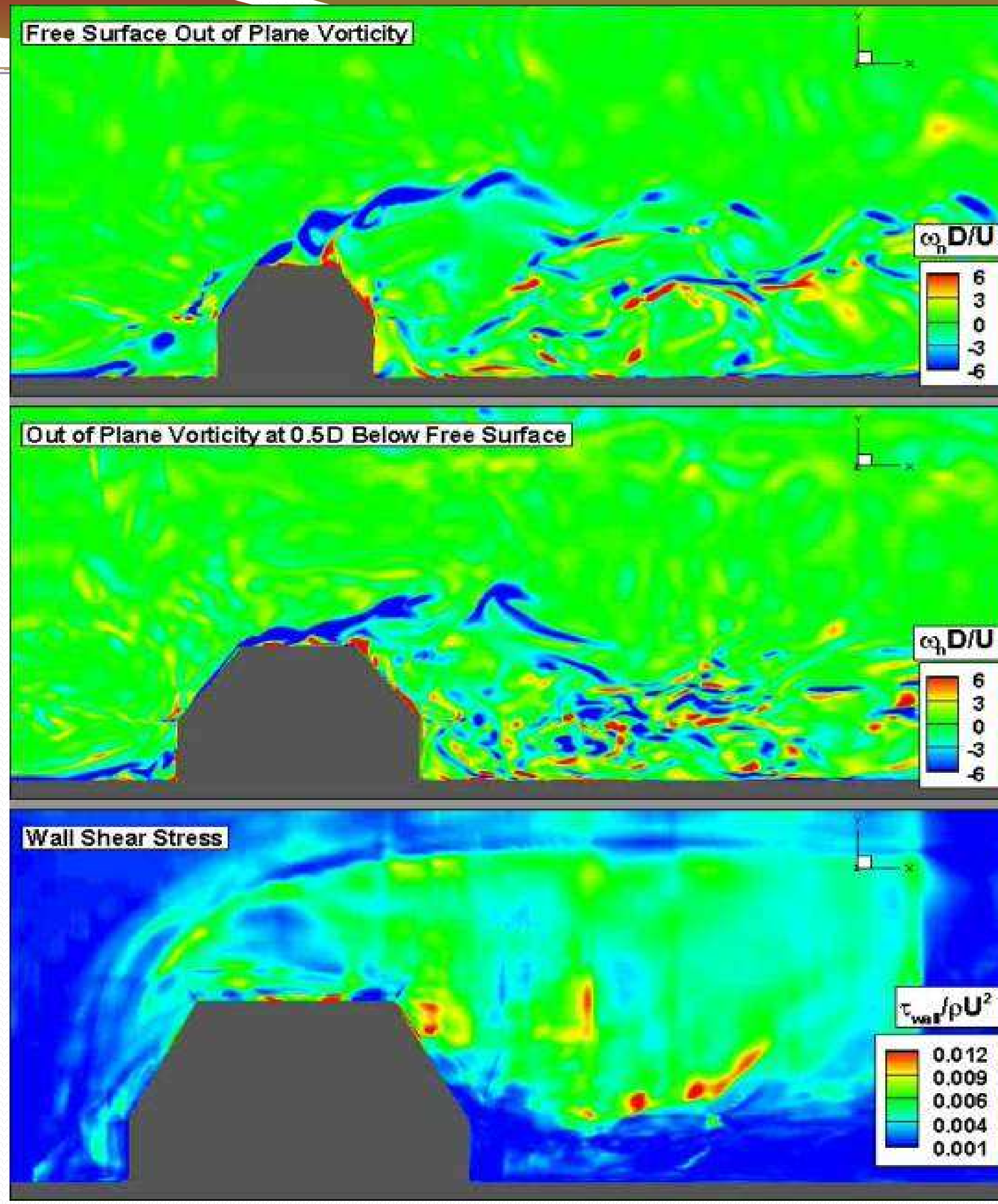
Total Scour Chart



Future Goals

- Model flow in 3-Dimensions for complex bridge geometries
- Physics-based scour prediction rather than empirical equations
- ➔ CFD (computational fluid dynamics)

CFD Modeling



Vortex Structures
At a Bridge Abutment

Dr. Constantinescu
University of Iowa

Lessons Learned

- Always have an Accurate Plot of the Historic Channel Cross-Sections relative to the Bridge Substructure
- Know what is going on beyond the limits of the channel cross-section by surveying if possible
- Learn the history of the river using aerial photographs
- Use 2-D Hydraulic Models to improve scour predictions
- Anticipate more accurate modeling of hydraulics and scour in the future using 3-D Modeling

Questions ?