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NHI Course No. 13047

Stream Stability and Scour at Highway Bridges

Bridge Inspectors Module - Participant Notebook

National Highway Institute

November 20, 1995

BRIDGE INSPECTOR'S MODULE
STREAM STABILITY AND SCOUR AT HIGHWAY BRIDGES

DETAILED LESSON SCHEDULE

Time	Length (min.)	Lesson	Topic	Method of Instruction	Resources	Reference
			INTRODUCTION			
8:00- 8:45	45	1	Introduction - Magnitude of the Problem	Lecture	Slides & Video	---
			STREAM STABILITY CONCEPTS			
8:45-10:00*	75	2	Stream Stability Factors and Principles	Lecture	Slides	HEC-20
10:15-10:45	30	3	Hatchie River Bridge Failure	Case Study	Slides	---
			BRIDGE SCOUR CONCEPTS			
10:45-11:15	30	4	Scour Concepts (long term, contraction, and local scour)	Lecture	Slides & Video	HEC-18
11:15-12:00	45	5	Scour Processes (contraction, pier and abutment scour)	Lecture	Slides	HEC-18
			COUNTERMEASURES AND INSPECTION			
1:00- 1:30	30	6	Countermeasures for Stream Instability and Scour	Lecture	Slides	HEC-20 HEC-18
1:30- 2:00	30	7	NBIS and Coding for Stream Instability and Scour	Lecture	Slides	HEC-18 Coding Guide
2:00- 3:00 3:15- 3:45	90	8	Scour Inspection Workshop	Workshop	Slides	-----
3:45- 4:15	30	9	Summary of Scour Inspection Procedures	Lecture	Slides	HEC-18
4:15- 4:30	15	10	Critique	Critique	Certificate	-----

* 15 minute mid-morning and mid-afternoon break (stretch break in place between lessons)

LESSON 1

INTRODUCTION

OVERVIEW: Method of Instruction: Lecture

Lesson Length: 45 minutes

Resources:

Lesson Outline
Slides
Video

OBJECTIVES: At the conclusion of this lesson, the Participant shall be able to:

1. **Understand** the magnitude of the stream stability and scour problem at highway crossings.

2. **Understand** the objectives of this module.

3. **Understand** the module outline, organization, materials, and relationship to HEC-18 and HEC-20, and NHI Course Nos. 13046 - "Stream Stability and Scour at Highway Bridges," 13054 - "Engineering Concepts for Bridge Inspectors," and 13055 - "Safety Inspection of In-Service Bridges."

LESSON 1

INTRODUCTION

I. HOST WELCOME

II. INTRODUCTION OF INSTRUCTORS

III. MAGNITUDE OF STREAM STABILITY AND SCOUR PROBLEM

A. There are about 575,400 highway bridges in the nation's National Bridge Inventory - 84% (483,158) are over streams or rivers.

B. Stream instability, long-term stream aggradation or degradation, contraction scour, local scour, and lateral scour or erosion cause 60% of the bridge failures in the United States.

C. Nationally, the annual cost for scour related bridge failures is about $30 million and flood damage repair costs for Federal-aid highways are about $50 million.

D. Results of National screening for scour vulnerability. As of April 15, 1995, 97.8% of the 483,158 bridges over streams or rivers have been screened into the following categories:

Categories	Number of Bridges	Percentage
Evaluation Complete		
Low risk culverts	97,215	20.1
Low risk bridges	106,156	22.0
Scour critical	7,105	1.5
Evaluation Needed		
Screened low risk	79,932	16.5
Scour susceptible	76,429	15.8
Not Screened	10,696	2.2
Evaluation Deferred		
Unknown foundations	105,625	21.9

E. Video of the Schoharie Creek bridge failure (April 5, 1987) illustrates the catastrophic results of instantaneous bridge failure due to scour and accompanying tragic loss of life. (Note: We will discuss the Schoharie Creek failure in more detail later in this lesson.)

F. An evaluation of road and bridge damage occurring during major floods in the United States during the 1980s indicates that the indirect costs of bridge failure can exceed the direct costs by orders of magnitude. Using the Schoharie Creek bridge and others damaged during the 1987 flooding in New York as examples, it was estimated that the indirect costs suffered by the general public, business, and industry because of long detours and lost production time exceed the direct cost of bridge repair by a factor of five.

G. Hatchie River bridge failure illustrates a failure caused by stream instability. The National Transportation Safety Board concluded:

> ". . . The probable cause of the collapse of the Northbound U.S. 51 spans was the northward migration of the main river channel which the Tennessee Department of Transportation failed to evaluate and correct. Contributing...was the lack of redundancy in the design of the bridge spans."

(Note: We will discuss the Hatchie River bridge failure in more detail in Lesson 3.)

H. Slides showing scour and stream stability problems at bridges at various locations in U.S. illustrate the extent of the problem.

I. On March 10, 1995, the I-5 bridges over Arroyo Pasajero near Coalinga, California, collapsed causing 7 deaths. Preliminary indications are that scour contributed to the failure. An investigation is in progress.

NOTES:

IV. MODULE OBJECTIVES

A. **Identify** stream instability and scour problems at bridges.

B. **Understand** the problems caused by stream instability and scour.

C. **Understand** the magnitude of scour at bridge piers and abutments and in the bridge reach.

D. **Recognize** potential countermeasures for stream instability and scour problems.

E. **Relate** scour and stream stability evaluations to the National Bridge Inspection Standards.

V. MODULE OUTLINE

A. A detailed module outline and schedule has been provided. For each lesson, the scheduled time, length, topic, and method of instruction are indicated. Also, a general reference for the material is indicated.

B. This module uses two primary sources of information:

Scour - FHWA Hydraulic Engineering Circular (HEC) No. 18, "Evaluating Scour at Bridges," updated 1995.

Stream Stability - FHWA Hydraulic Engineering Circular (HEC) No. 20, "Stream Stability at Highway Structures," updated 1995.

The material contained in this workbook is presented in more detail in these references which can be obtained from FHWA. Some material has been abbreviated to meet the needs of the bridge inspector, and some equations have been rearranged algebraically to provide a better qualitative understanding of the relationships among variables.

C. In addition, Report No. FHWA-ED-89-044, December 1988, "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges," is used as a supporting report for the module.

D. Other important sources of information are referenced when used in the Workbook.

E. This module summarizes the most relevant information for bridge inspectors from the longer course "Stream Stability and Scour at Highway Bridges" National Highway Institute (NHI No. 13046). The module provides detailed supplementary information on scour and stream stability for those who have taken or will take the courses on "Engineering Concepts for Bridge Inspectors" (NHI No. 13054) or "Safety Inspection of In-Service Bridges" (NHI No. 13055).

VI. SCHOHARIE CREEK BRIDGE FAILURE

A. A brief overview of the Schoharie Creek Bridge failure illustrates the potential catastrophic results of scour. Reference will be made to the Schoharie Creek failure during the day to illustrate other points.

1. **The Setting**.

On Sunday, April 5, 1987, at about 10:45 a.m. (EDT), the center span (Span 3) and east center span (Span 4) of the 165-meter-long bridge on the New York State Thruway over Schoharie Creek in Montgomery County, New York, collapsed during a near record flood (1,756 m^3/s). About an hour and a half later the west center span (Span 2) fell into the water and the western-most span (Span 1) slid off the abutment (see photograph). One tractor semi-trailer and four automobiles fell nearly 25 meters into the river after the first span collapsed, resulting in ten fatalities.

The National Transportation Safety Board (NTSB) retained consultants to determine the role that erosion, scour, and hydraulic forces may have played in the collapse of the Schoharie Creek Bridge. The study supported the broader investigation of the Board which included such areas of inquiry as: bridge design, bridge construction, bridge inspection and maintenance, emergency planning, and Federal and State oversight responsibilities. The study was co-sponsored by the New York State Thruway Authority (NYSTA). This information was derived from the final consultant's report.

Schoharie Creek is the largest tributary of the Mohawk River. Rising in the Catskill region, the Schoharie flows northerly into the Mohawk at Fort Hunter (see location map). The USGS reports a drainage area of 2287 km^2 above the Burtonsville gage. The upper reaches

PHOTOGRAPH OF SCHOHARIE CREEK BRIDGE ABOUT 15 MINUTES AFTER INITIAL FAILURE, VIEW IS LOOKING SOUTH (UPSTREAM) WITH WEST ABUTMENT ON RIGHT (BY SIDNEY BROWN)

are mountainous while the lower watershed is made up of rugged, rounded hills. This topography coupled with a relatively impervious soil leads to rapid runoff and high flood flows. Schoharie Creek is 134 km long and has an average gradient of 0.0086, m/m.

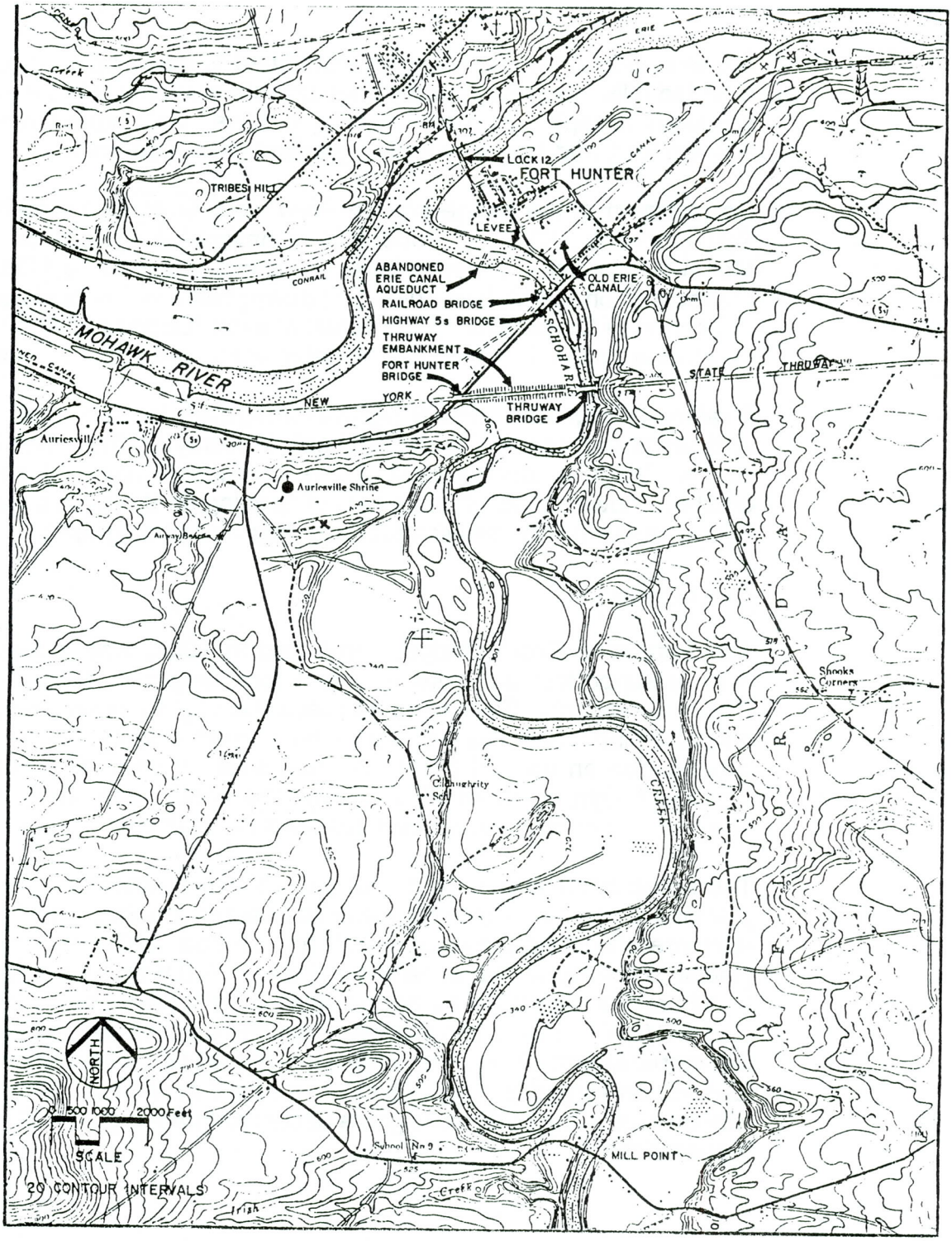
Downstream of the bridge site the New York State Department of Transportation (NYSDOT) operates a navigation system on the Mohawk river with a series of locks and dams. Lock 12 and Dam 8 are located on the Mohawk river just downstream of the confluence of Schoharie Creek. During the winter season (December-April) the navigation system is closed and all gates are raised out of the water.

A railroad bridge and another highway bridge are located about 610 m downstream of the Schoharie Creek Thruway Bridge. The Fort Hunter Bridge is located west of the Thruway Bridge and during overbank flows can function as a relief opening for the main channel bridge crossing (see detailed location map and photograph).

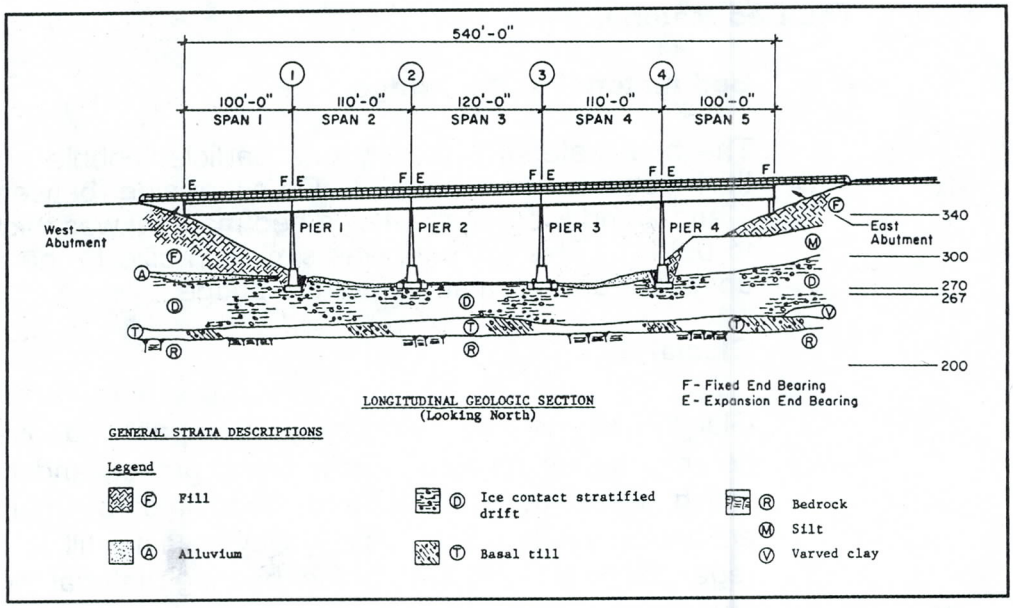
2. **The Bridge**.

The Schoharie Creek Bridge, completed in 1954, was a 5-span, "simply supported" structure having a total length of 165 m (see "South Elevation"). Each span was separated by an expansion joint and acted independently (i.e., they were nonredundent). The bridge was built on an upward 3% grade from west to east, and had an average height of about 25 m above the creek. Alignment was straight, and each roadway was crowned for drainage.

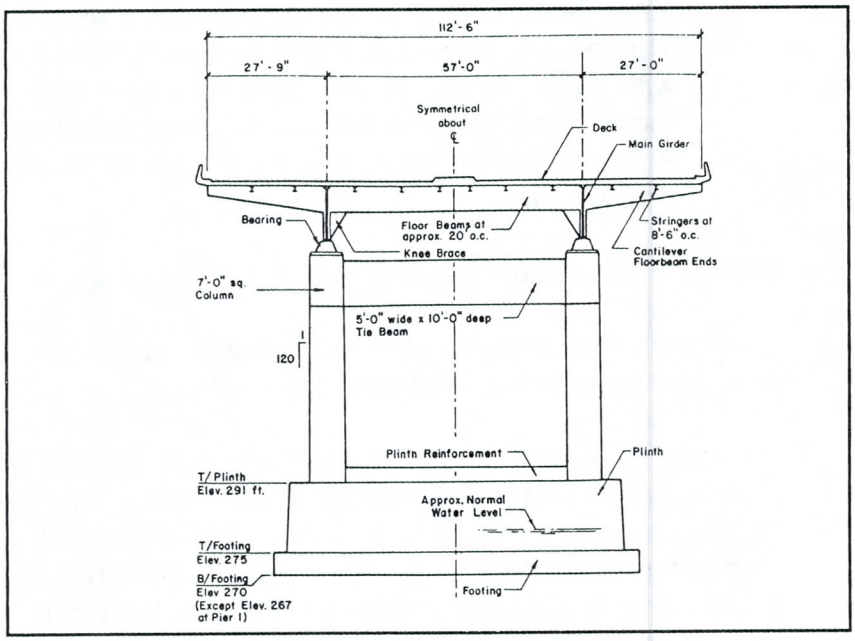
The substructure consisted of four piers and two abutments. Each pier was a rigid frame (columns and tie beam) supported on a lightly reinforced concrete plinth (pedestal) and spread footing bearing on glacial till just below the streambed (1.5 m). A 0.9 m deep element (plinth reinforcement) was added after construction (see "Cross-section View"). The abutments were founded on piles driven through the embankment fill into the underlying glacial till. The piers were founded on <u>spread footings</u> 1.5 m deep by 5.5 m wide by 25 m long with no piles. The bridge designers assumed that the glacial till was "nonerodable."



SCHOHARIE CREEK DETAILED LOCATION MAP FROM MILL POINT TO THE MOHAWK RIVER



SOUTH ELEVATION - SCHOHARIE CREEK BRIDGE SHOWING KEY STRUCTURAL FEATURES AND A SCHEMATIC GEOLOGICAL SECTION



CROSS SECTION VIEW OF TYPICAL PIER SUPPORT SYSTEM SCHOHARIE CREEK BRIDGE

3. **The Bed Material.**

a. **Bed material at the bridge.**

The bed material was only one particle (cobble size) size thick between Piers 2 and 3. On either side (between Piers 1 and 2 and Piers 3 and 4) the bed material was thicker (0.3 to 0.9 m). This material was similar in size to the material upstream and downstream of the bridge.

b. **Glacial till.**

Glacial till is an extremely compact, dense, and heterogeneous mixture of silt, sand, gravel, and boulders which were transported and deposited by glacial ice advancing up the Schoharie Valley. Glacial till is typically regarded as a highly satisfactory bearing material for spread foundations; however, it is important to recognize that it is erodible by moving water. Flume tests at Cornell University using clear water flowing over samples of the glacial till taken from the Schoharie Creek bed showed that **some material would be removed at velocities of 1.49 m/s or larger**. At velocities of 2.44 m/s the erosion rates were relatively large. These tests subjected the sample to simple horizontal shear with clear water. In very turbulent flow with abrasion from moving sediment the erosion of this material would be higher. Also, seams or areas of less dense till would increase the erosion rate.

4. **Riprap Protection - Piers 2 and 3.**

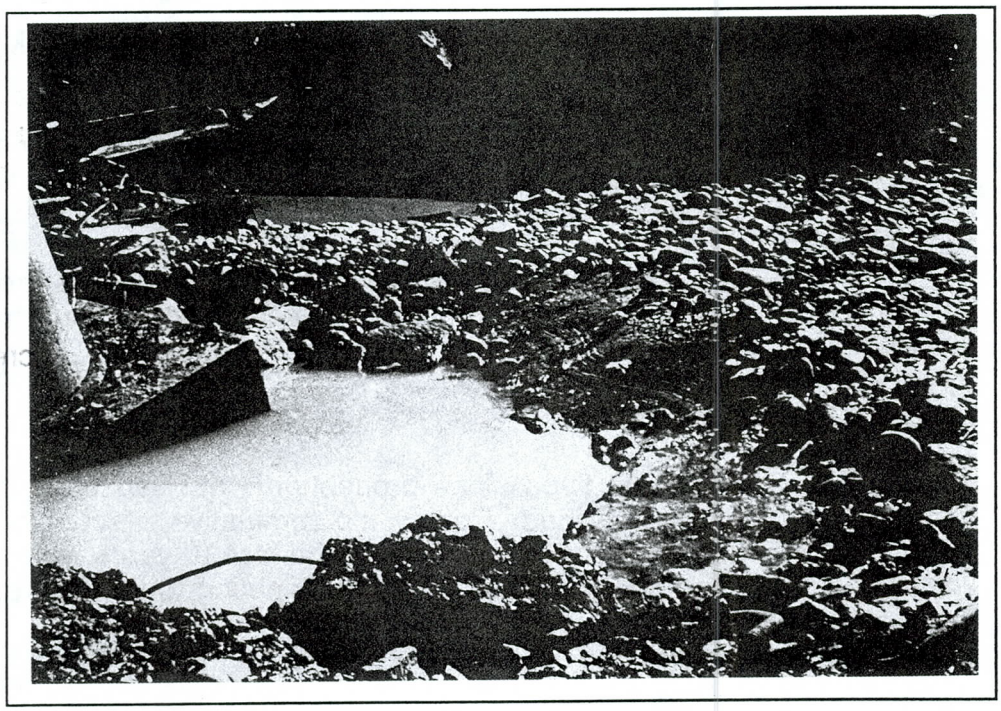
New York Department of Public Works (NYDPW), Item 80 was specified for placement around the piers:

"At least 50% of the stones shall weigh in excess of 300 pounds (136 kg) each and the remainder of the stones shall weigh from 100 to 300 pounds (45 to 136 kg) each. One dimension of each of the stones furnished shall be the thickness of the riprap as shown on the plans, and the stones shall be so laid that this dimension is perpendicular to the prepared bed."

B. **Conclusions.**

1. **Probable Cause.**

"The National Transportation Safety Board determined that the probable cause of the collapse of the Schoharie Creek bridge was the failure of the New York State Thruway Authority to maintain adequate riprap around the bridge piers, which led to severe erosion in the soil beneath the spread footings. Contributing to the accident were ambiguous plans and specifications used for construction of the bridge, an inadequate NYSTA bridge inspection program, and inadequate oversight by the New York State Department of Transportation and the Federal Highway Administration. Contributing to the severity of the accident was the lack of structural redundancy in the bridge."



2. **Channel Stability and Scour.**

- Schoharie Creek is a stable channel and there has been no long-term bed elevation change at the Thruway Bridge since it was built in 1954.

- The location of the bridge downstream of the bend concentrated the flow in the right half of the channel. Thus, scour potential at Pier 3 was substantially greater than at the other piers.

- Local scour at Pier 3 undermined the footing. Velocities and scour pattern around the pier were affected by the exposure of the footing.

- Significant scour at Pier 2 did not occur until after Pier 3 failed, placing debris in the flow that intensified velocities at Pier 2.

3. **Riprap**.

- Measurement of velocity around Pier 3 in the model study showed velocities to be larger than approach conditions and extremely turbulent.

- Item 80 riprap did not require sufficiently large rock to resist the turbulence and velocity at Pier 3.

- Velocities and turbulence at Pier 3 were sufficiently strong to erode glacial till in the vicinity of the pier when the till is exposed to the flow.

- If sufficiently large riprap had been maintained around the piers, it is highly probable that the bridge would not have failed.

4. **Cumulative Effects**.

- The 1987 flood alone probably did not cause failure of the Thruway Bridge. Rather, the cumulative effect of local scour around Pier 3, particularly in the last 10 years, was the most significant hydraulic factor contributing to the failure.

5. **Bridge Inspection**.

- New York State Thruway Authority inspections of the Schoharie Creek Bridge did not document the elevation or condition of the streambed or underwater elements of the substructure.

- Bridges with piers that have shallow spread footings and riprap for protection from scour require more frequent and more thorough inspections if the water has the potential to be turbulent than do bridges located in placid water.

- Structural members and foundation features critical to the integrity of the bridge were not highlighted in the design plans or recognized by the bridge inspectors.

- Inspectors (and some supervisors) from the New York State Thruway Authority, the New York State Department of Transportation,.....either failed to understand the importance of riprap or failed to recognize that sufficient riprap had migrated from around Piers 2 and 3 to pose a danger to the bridge.

VII. ADMINISTRATIVE NOTES

A. **Facilities, Breaks, Lunch, etc.**

B. **Workshops and Case Studies.**

C. **Module Evaluation.**

NOTES:

LESSON 2

STREAM STABILITY FACTORS AND PRINCIPLES

OVERVIEW: Method of Instruction: Lecture

Lesson Length: 75 minutes

Resources:

Lesson 2 Outline
Slides
HEC-20, (Chapters 2.0 and 3.0)
HEC-20 Glossary (attached following Lesson 9)

OBJECTIVES: At the conclusion of this lesson, the Participant shall be able to:

1. **Understand** the factors influencing stream stability.
2. **Understand** several basic concepts describing channel response.
3. **Define** the water and sediment continuity concepts.
4. **Understand** the concept of resistance to flow in sand-bed channels.

LESSON 2

STREAM STABILITY FACTORS AND PRINCIPLES

I. RIVER PROCESSES

A. **Rivers** are dynamic, always changing their position, shape and other morphological characteristics with variation in discharge and the passage of time.

B. When a channel at or near a bridge is modified, this local change frequently causes modification of channel characteristics both up- and downstream. Conversely, channel modifications above or below the bridge reach can affect channel characteristics in the bridge reach.

C. Understanding river processes and the stream stability factors will assist in coding the scour and stream stability related items of the NBIS, including:

Item 60 - Substructure
Item 61 - Channel and Channel Protection
Item 71 - Waterway Adequacy
Items 92 and 93 - Critical Feature Inspection
Item 113 - Scour Critical Bridges

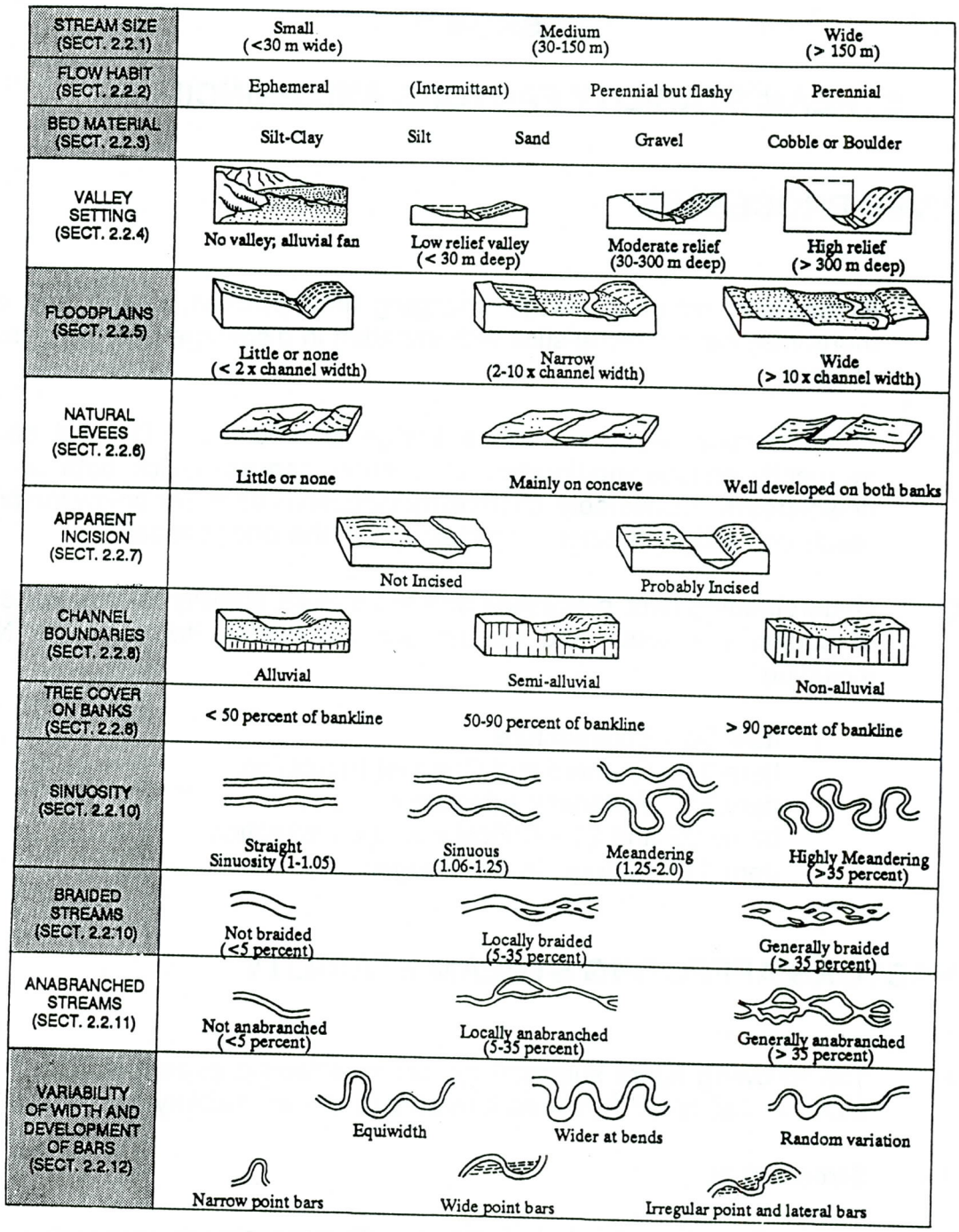
II. FACTORS AFFECTING STREAM STABILITY

A. The following figure summarizes factors affecting stream stability. Each factor is discussed below as it relates to stream stability and scour.

1. **Stream Size**.

a. Flow depth tends to increase with increasing stream size, and the potential for scour increases with increasing depth. Therefore, potential scour depth increases with increasing stream size.

b. Lateral erosion potential also increases with increasing stream size.



FACTORS THAT AFFECT STREAM STABILITY

Shaded sections indicate factors most important to Bridge Inspectors
Section references are related to sections in Chapter 2, HEC-20

2. **Flow Habit**.

   a. **Ephemeral**--flows in direct response to rainfall (includes intermittent streams).

   b. **Perennial, but flashy**--flows all or most of the year, but responds to precipitation by rapid changes in stage and discharge.

   c. **Perennial**--flows all or most of the year.

3. **Bed Material**.

   a. Streams can be classified by the dominant size of sediment on their beds.

   b. There is no direct relation between bed material size and incidence of scour problems at bridge crossings, although deep scour holes are generally more probable in fine bed material.

   c. All bed material can erode, even bedrock--it only takes more time.

4. Valley Setting.

   a. Streams in mountainous regions, or areas of high relief often have no hydraulic problems at bridge crossings due to coarse bed material, narrow floodplains, nonalluvial type conditions.

   b. In contrast, streams in regions of lower relief are usually alluvial and have more problems due to more active channels.

   c. There are special problems related to alluvial fans.

5. **Floodplains**.

   a. Floodplain width affects the length of the highway crossing, composed of the approach embankment(s) and the bridge.

   b. For longer highway crossings there are usually more bridge components exposed to flow.

6. Natural Levees.

   a. Form during overbank flow conditions.

   b. When well developed, natural levees tend to limit lateral migration.

7. Apparent Incision.

   a. Determined by bank height at normal stage relative to width.

   b. Incised streams tend to be fixed in position with slow lateral migration rates, except for western arroyos with high, vertical and clearly unstable banks.

8. **Channel Boundaries**.

   a. Channel boundaries may be alluvial, semialluvial, or nonalluvial. Alluvial channels may be defined as channels that are formed in materials that have been and can be transported by water. Nonalluvial channels may be defined as channels in bedrock or in very large material (cobbles or boulders).

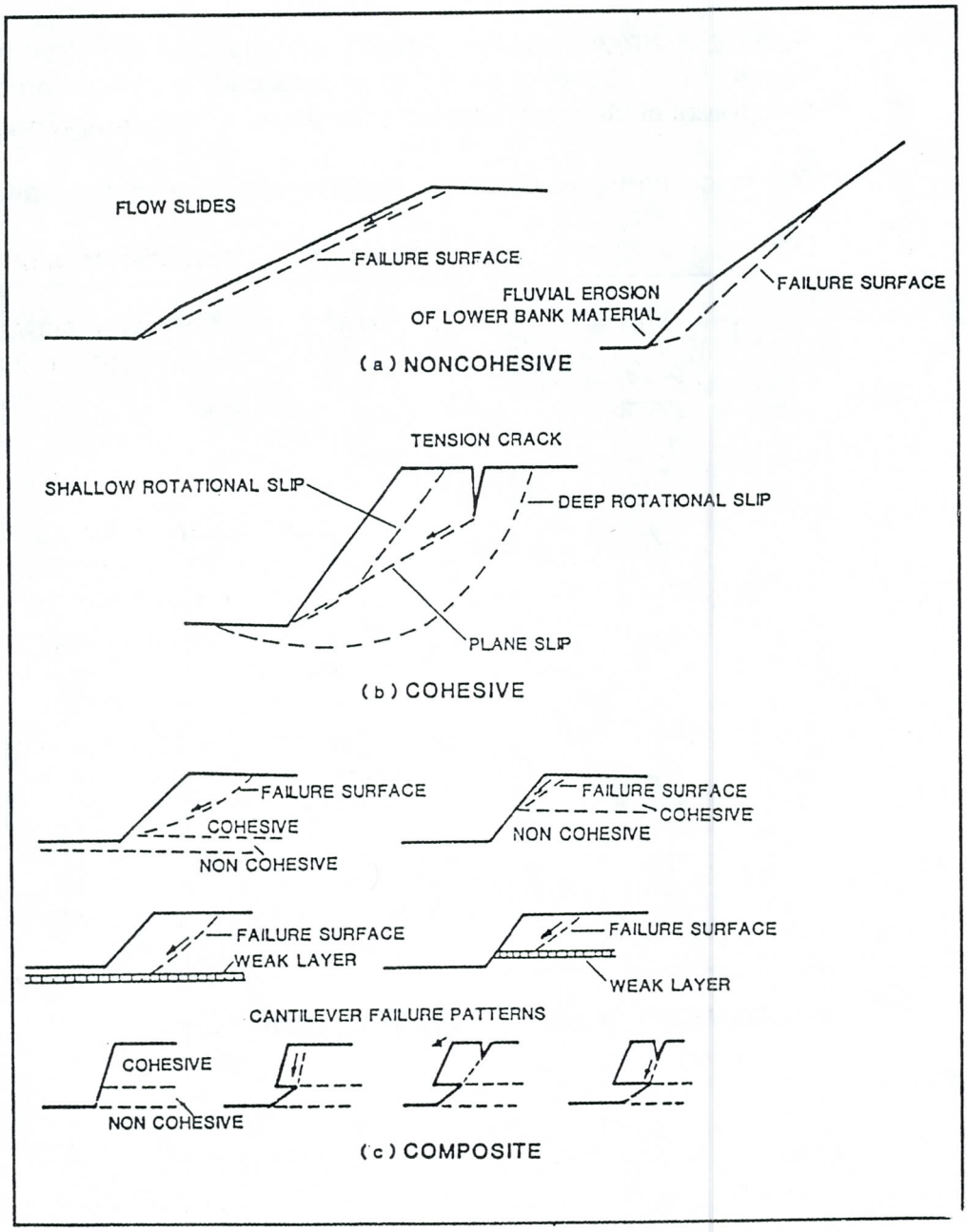
   b. Alluvial streams are generally more susceptible to stream instability than nonalluvial; however, the quality of bedrock in a stream considered nonalluvial must be considered.

   c. In alluvial channels, approximately 90% of all channel changes occur during flows greater than the dominant discharge, which typically occur less than 10% of the time.

   d. Bank appearance is a good indicator of stability.

   e. Types of bank failure (see figure).

   f. Tree cover or vegetative cover on the channel banks or overbank (riparian vegetation) can provide stability against lateral channel erosion.

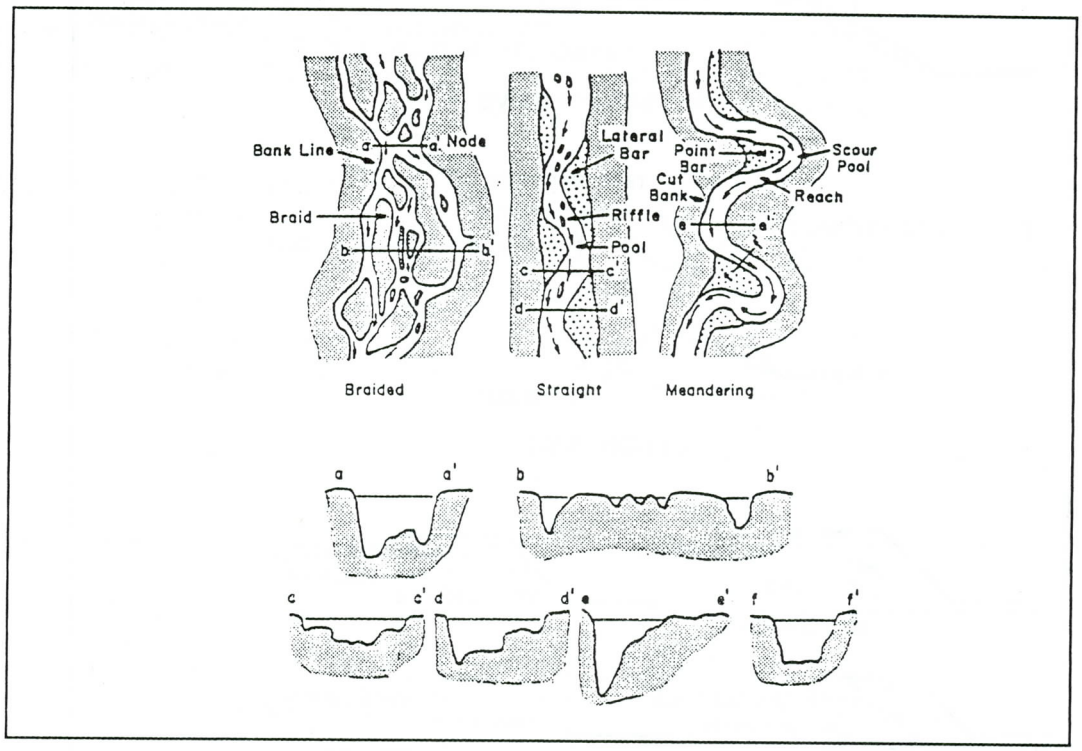


TYPICAL BANK FAILURE SURFACES:
(A) NONCOHESIVE, (B) COHESIVE, AND (C) COMPOSITE

9. **Stream Planform.**

a. A study of stream planform, that is the shape of the stream when viewed from above, is useful in understanding stream processes and potential stream response to change.

b. The following figure illustrates the three basic planform patterns.



RIVER CHANNEL PATTERNS

c. **Meandering streams.**

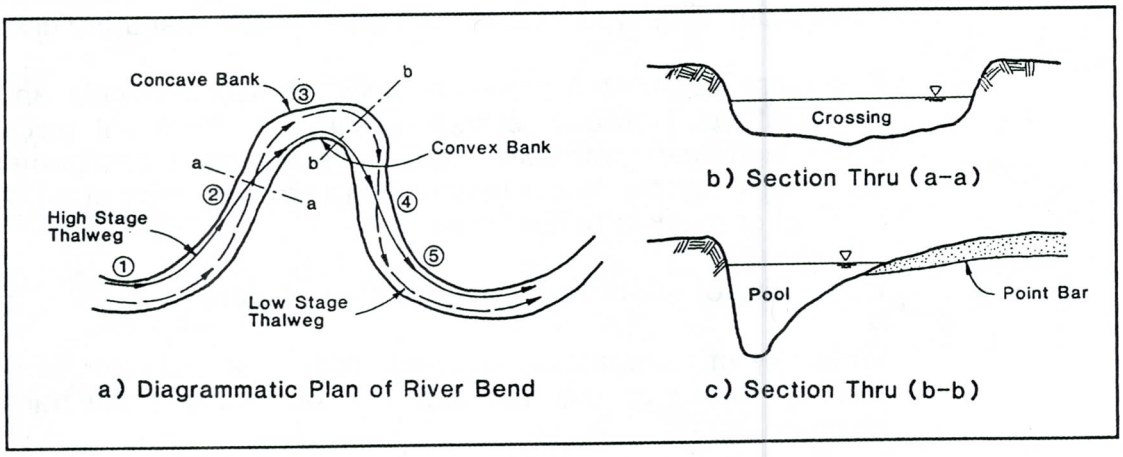
A meandering channel consists of pools and crossings, with the thalweg (deepest point in the cross section where the main current is flowing) flowing from pool to pool through the crossings in an S-shaped alignment.

The degree of meandering is described by **sinuosity**, defined as the ratio of the thalweg distance to valley distance. Straight channels have a sinuosity of one. **There is no direct relationship between the degree of sinuosity and lateral instability (see Item g below).**

For a meandering stream, erosion generally attacks the outside of the meander bend. Deposition occurs on the point bar on the inside of the bend.

The position of the main current (thalweg) changes from low flow to high flow.

Formation of cutoffs and oxbow lakes.



CHARACTERISTICS OF A RIVER BEND

d. **Straight streams.**

Alluvial channels of all types deviate from a straight alignment and generally, a straight channel is considered a transitional stage to meandering.

Even in straight channels, the thalweg will meander.

Straight channel reaches of more than 10 channel widths are not common in nature.

e. **Braided streams.**

A braided stream consists of multiple and interlacing channels.

Braiding is usually associated with large bed-load transport and/or easily eroded channel banks.

Braided streams are unstable and change alignment rapidly.

f. Anabranched streams.

Anabranched streams are somewhat similar to braided streams; however, in an anabranched channel the individual braids, or channels, are more widely and distinctly separated and more fixed in position. This type of stream is often called island braided.

The more permanent nature of anabranched channels and the probability of individual branches carrying significant discharge under high flow complicates the diversion and/or confinement of flow. This can result in a larger bridge crossing than at a braided channel or multiple bridge crossings.

g. **Variability of width and development of bars.**

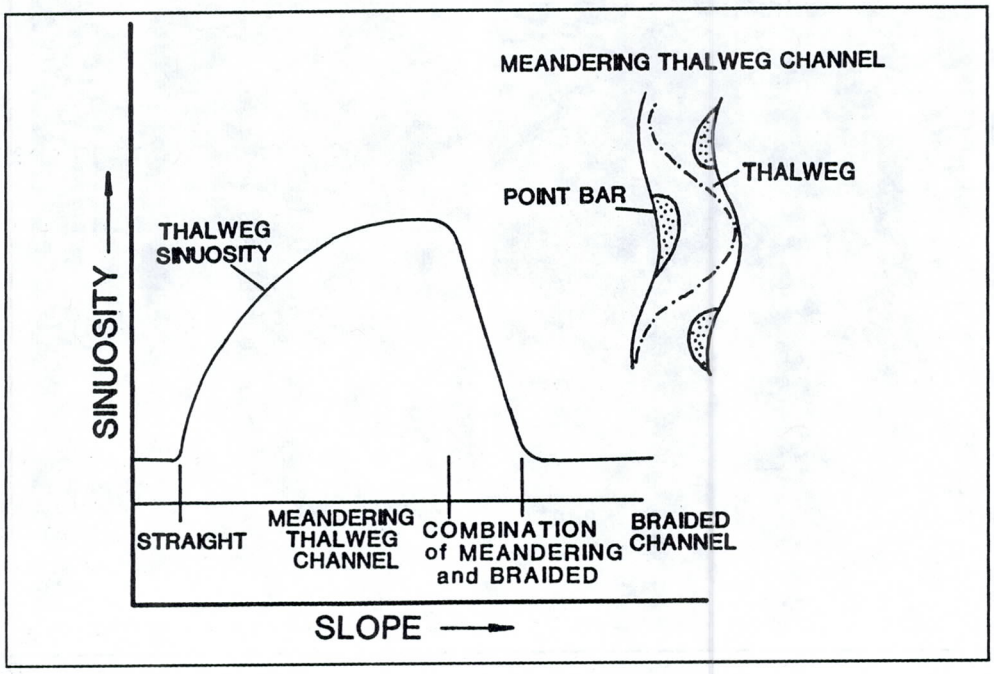
Variability of unvegetated channel width is an indicator of lateral stability, based on the rate and development of point bars and alternate bars.

In general, equiwidth streams with narrow point bars are the most stable laterally, while random-width streams with wide, irregular point bars are least stable.

III. CONCEPTS DESCRIBING CHANNEL RESPONSE

A. Analyzing Planform Response.

1. Stream form-slope relationship (see figure).



SINUOSITY VS. SLOPE WITH CONSTANT DISCHARGE

2. Channel pattern (planform) can change from straight to meandering to braided depending on the slope.

3. Channel instability as a result of natural processes or human activity can be propagated for long distances and affect structures such as bridges located upstream or downstream from the area of disturbance.

B. Armoring in Alluvial Channels.

1. Development of an armor layer (coarser particles on the surface of the bed) can protect the bed up to the discharge sufficient to disrupt the armor layer itself. Even then, the armor layer can reform as flows diminish.

2. The armoring process begins as the non-moving coarser particles segregate from the finer material in transport. The coarser particles gradually accumulate in a layer which can prevent the underlying fine material from leaching through the "armor" layer and can arrest degradation.

3. Investigations and observations support the conclusion that less than a complete covering of a relatively thin armor layer plays a key role in stabilizing the bed, bars, and islands of alluvial rivers.

4. An insignificant fraction of the alluvium (perhaps the coarsest 1 percent) may significantly control the behavior and morphology of the channel.

IV. CONTINUITY OF FLOW

A. Water Continuity Concept.

1. Continuity Equation.

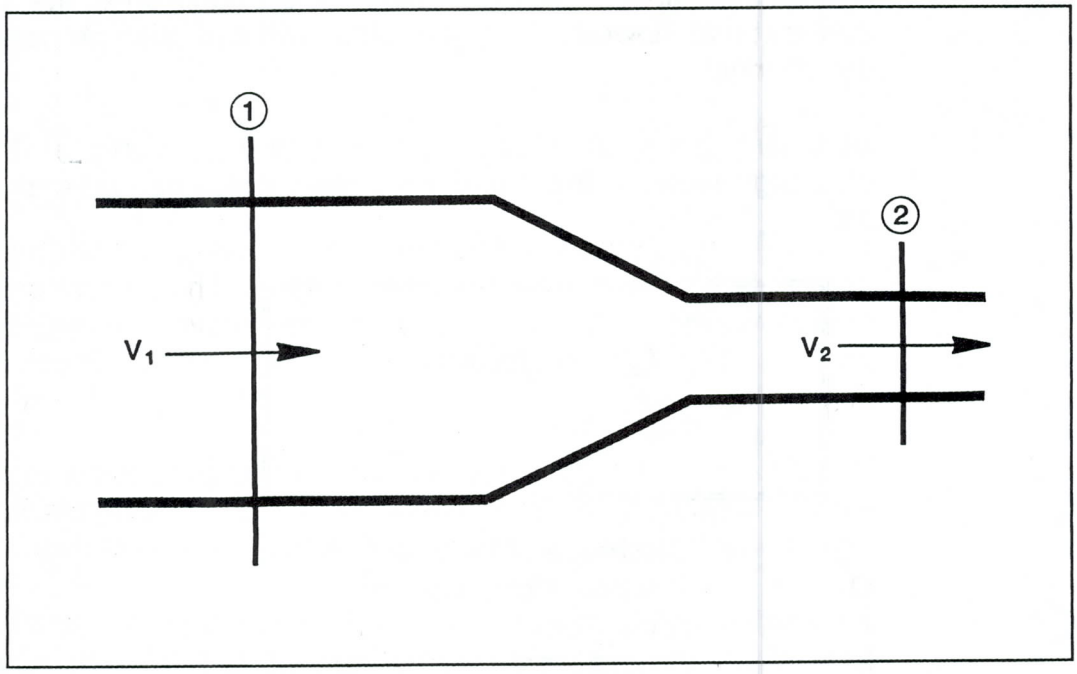
$$Q = V A$$

where

Q = Discharge, m^3/s

V = Mean velocity, m/s

A = Area of flow, m^2



CONTINUITY CONCEPT

As the flow goes from the larger flow section A_1 to the smaller flow section A_2, continuity tells us:

$$Q_1 = Q_2$$

and:

$$A_1 V_1 = A_2 V_2$$

What happens to the velocity from section 1 to section 2?

B. Sediment Continuity Concept.

1. It is important to know the distinction between sediment transport **capacity** and sediment **supply**.

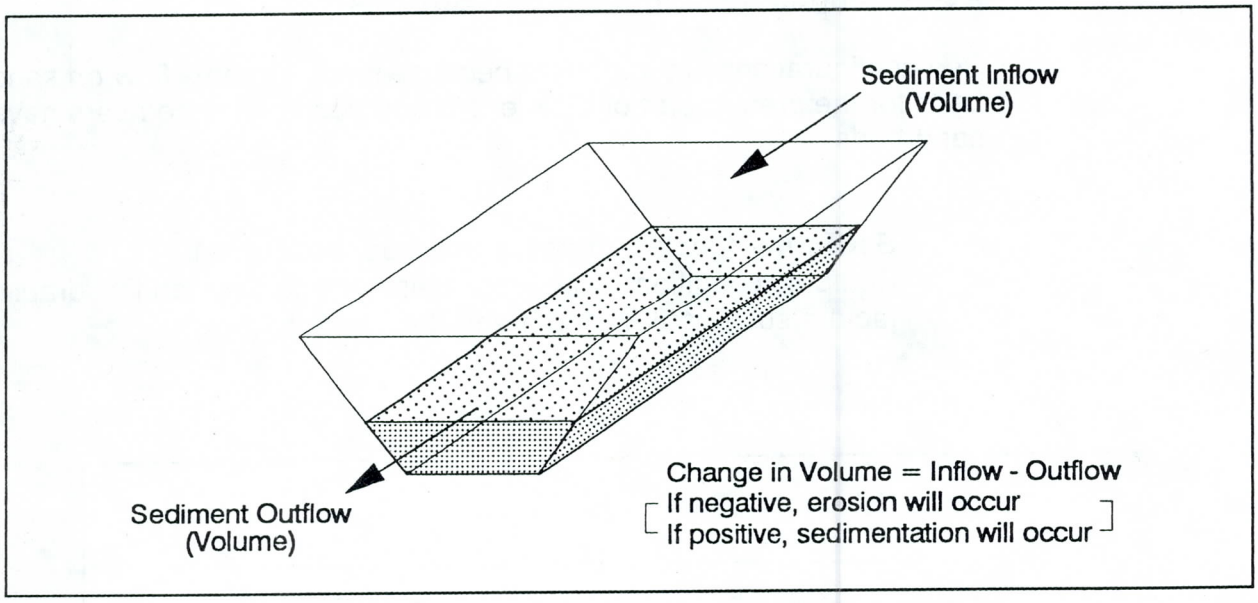
   Sediment supply is primarily that sediment provided to the channel from watershed, tributary flow, and the channel bed and banks. **Sediment transport capacity** can be considered the actual physical capability of the channel to transport sediment, as defined by flow conditions. Transport capacity is a function of the size of bed material, flowrate, and geometric and hydraulic properties of the channel.

2. Sediment transport capacity is generally proportional to the discharge (flow) to the 1.5 to 2.5 power, which can be expressed as:

$$\boxed{Q_s = aQ^b}$$

Q_s	=	Discharge of sediment, m^3/sec
Q	=	Discharge of water, m^3/s
a	=	A coefficient
b	=	An exponent ranging from 1.5 to 2.5

3. Definition of sediment continuity (see figure).



DEFINITION SKETCH OF SEDIMENT CONTINUITY CONCEPT APPLIED TO A GIVEN CHANNEL REACH OVER A GIVEN TIME PERIOD

4. If the inflow of sediment equals the outflow of sediment, the river reach will be in equilibrium (no change).

5. If the inflow of sediment is greater than the outflow of sediment, aggradation (sedimentation) will occur in the river reach.

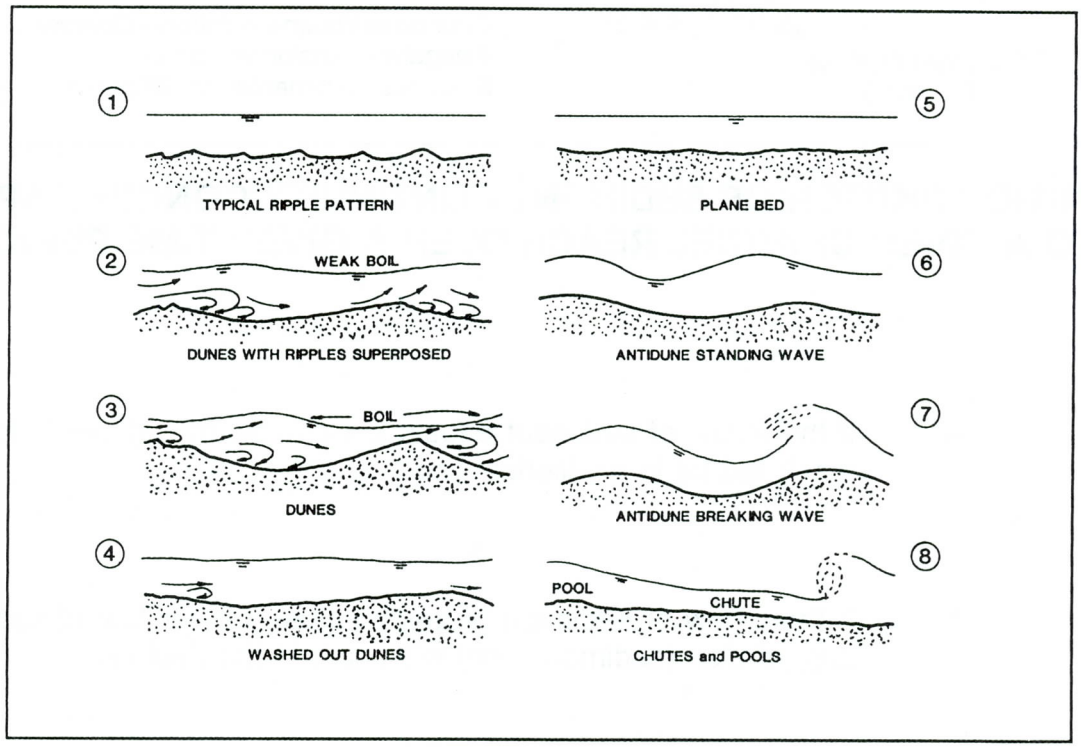
6. If the inflow of sediment is less than the outflow of sediment, degradation will occur in the river reach.

V. SAND-BED CHANNELS

1. Bed Configurations in Sand-Bed Streams.

Bed configurations are important because many streams flow on sand beds for the greater part of their length and nearly all large rivers have sand beds.

a. **Bedforms** (ripples, dunes, plane bed, antidunes).
Bedform condition influences resistance to flow and hydraulic factors such as flow depth and flow velocity.



FORMS OF BED ROUGHNESS IN SAND CHANNELS

b. **Flow regime in sand-bed channels.**

Upper Flow Regime. In upper flow regime (conditions 5-8, above), resistance to flow is small and sediment transport is large. The water surface is in phase with the bed surface (typically plane bed or antidunes).

Lower Flow Regime. In lower flow regime (conditions 1-4, above), resistance to flow is large and sediment transport is small. The water surface is out of phase with the bed surface (ripples or dunes).

c. **Effects of bedforms.**

Care must be taken in analyzing bridge crossings on sand-bed streams in order to anticipate changes that may occur in bedforms and the impact that may occur from changes in resistance to flow, sediment transport, and stream stability.

At high flows, most sand-bed channels shift from dune bed to plane bed, which reduces resistance to flow, increases velocity, and decreases depth.

Dunes or antidunes can increase total scour depth due to passage of dune troughs, which effectively lower the datum or baseline elevation of the channel bottom.

Bedforms and bars also can change flow direction in a channel. At low-flow, bars can be residual causing high velocity flow along or at a pier or other structures, with potentially deeper scour occurring.

In evaluating a bridge or countermeasure, it is good practice to assume a dune bed (large n value) for water surface profile analysis, and plane bed (small n value) for evaluation of channel stability. Why?

2. **Bed material gradation.**

a. Silt-clay.

b. Silt.

c. Sand.

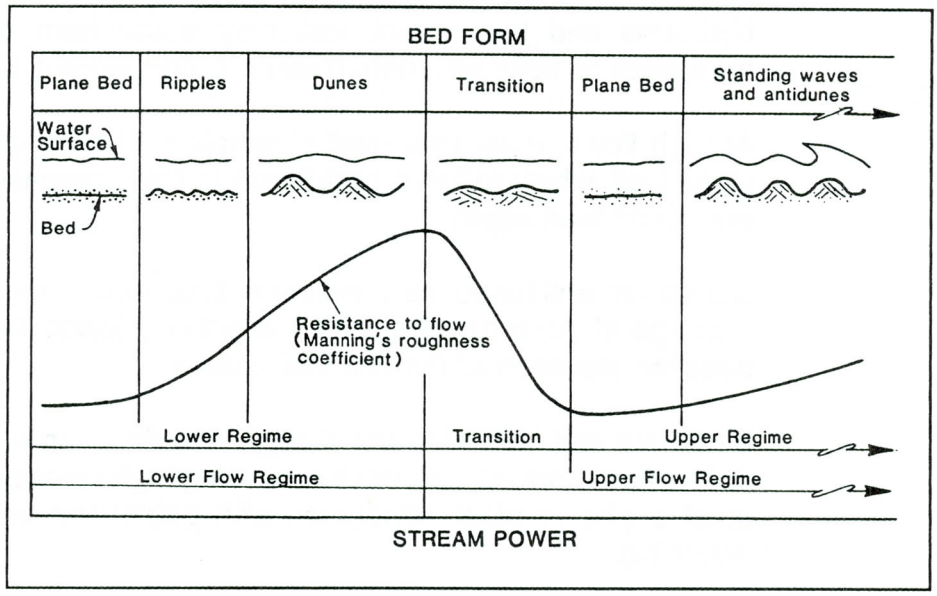
d. Gravel.

e. Cobbles-boulders.

D_{50} represents the diameter of the sediment particle for which 50 percent of the sample is finer by weight.

3. **Resistance to Flow in Sand-bed Channels.**

The following figure illustrates the relative resistance to flow as bed forms change with increasing stream power.



RELATIVE RESISTANCE TO FLOW IN SAND-BED CHANNELS

Common values of Manning's n (resistance coefficient) are given in the following table (see HEC-20, Chapter 3 for more details).

Manning's roughness coefficients for alluvial sand-bed channels (no vegetation).[1]	
Lower Flow Regime	
Plane bed	0.014 - 0.020
Ripples	0.018 - 0.030
Dunes	0.020 - 0.040
Transition	
Washed out dunes	0.014 - 0.025
Upper Flow Regime	
Plane bed	0.010 - 0.013
Standing Waves	0.012 - 0.015
Antidunes	0.012 - 0.020
[1]Data are limited to sand channels with $D_{50} < 1.0$ mm.	

LESSON 3

CASE STUDY - THE HATCHIE RIVER BRIDGE FAILURE

OVERVIEW: Method of Instruction: Lecture

Lesson Length: 30 minutes

Resources:

Lesson 3 Outline
Slides
NTSB Highway Accident Report "Collapse of the Northbound U.S. Route 51 Bridge Spans Over the Hatchie River near Covington, Tennessee, April 1989" (June 1990)
USGS Open File Report 89-598 "Channel Evaluation of the Hatchie River near the U.S. Highway 51 Crossing" (1989)
FHWA Report "April 1989 Hatchie River, U.S.51 Bridge Failure" (TRB, January 1990)

OBJECTIVES: At the conclusion of this lesson, the Participant shall be able to:

1. **Understand** the role of stream instability (lateral migration) in the failure of the Hatchie River bridge.

2. **Understand** the role of bridge inspection in the bridge failure.

LESSON 3

CASE STUDY THE HATCHIE RIVER BRIDGE FAILURE

I. INTRODUCTION

A. About **7:14 p.m.** central standard time on April 1, 1989, traffic was moderate on the northbound U.S. Route 51 bridge over the Hatchie River near Covington, Tennessee. At that time, the Hatchie River was above flood stage, covering the floodplain with about 3 to 4 ft (1 m) of water and the weather was cloudy and dry. A motorist traveling across the center of the bridge about **7:15 p.m.** encountered a depression in the bridge deck and stated that it felt as though her car hit a large board in the road. Later that evening, about **8:10 p.m.**, a motorist traveling about 50 mph (80 km/hr) across the bridge struck what she described as a "v" shaped depression in the deck just north of the center span, which nearly caused her to lose control of her vehicle. About **8:13 p.m.**, a motorist traveling about 55 mph (88 km/hr) over the center of the bridge crossed a "drop in the road," which caused the undercarriage of his truck to strike the bridge deck. About the same time, another motorist struck the depression in the deck causing him to strike his head on the vehicle's ceiling. This driver stated that the depression was about 2.5 to 3 ft (1 m) deep.

About **8:15 p.m.**, another motorist stated that while traveling northbound across the bridge, he encountered a "3-ft" (1 m) depression in the bridge deck, just north of the center span. After crossing this section of the bridge, the motorist observed two sets of vehicle headlights in his rearview mirror. He stated that the first vehicle disappeared from view. Following this observation, the motorist continued north about 3 miles (5 km) to Henning, Tennessee, to report the incident. Concurrently, a passenger car with 2 occupants was traveling northbound across the bridge. Both occupants stated that they encountered a deep depression in the bridge deck north of the center span, which caused them to strike their heads on the vehicle's ceiling. After crossing the depression, they continued northbound for a short distance before stopping, and then observed a vehicle behind them fall into a void in the bridge deck where the depression had been. Simultaneously, they heard a loud "rumbling noise." Shortly afterwards, they watched several more vehicles and a tractor-semitrailer drive into the void. These witnesses then drove about 1.5 miles (2.4 km) to a rest stop north of the bridge and telephoned the Ripley, Tennessee, Police Department to report the incident.

Also, about **8:15 p.m.**, a driver and 2 passengers of a van were traveling about 50 to 55 mph (80-88 km/hr) northbound on the bridge. The drive stated that he was traveling in the right lane behind a tractor-semitrailer that was preceded by 2 vehicles. The van operator began to move to the left lane to pass when the truck suddenly moved into the left lane in front of the van. Several seconds later, the van operator observed the taillights of the trailer shift "from side to side, kick up in the air," and then disappear along with the 2 vehicles which were ahead to the truck. Following this observation, the van operator stopped his vehicle approximately 12 ft (4 m) from the edge of the void. The operator and passengers exited the van, looked over the edge of the bridge, and observed the semitrailer floating in the river. The van occupants then proceeded south on foot and stopped oncoming traffic.

The Ripley Police Department was notified of a deep depression in the bridge deck at **8:19 p.m.**, and subsequently advised the Lauderdale County Sheriff's Department which dispatched a sheriff's deputy to investigate the complaint. Shortly thereafter, both the Lauderdale and Tipton County Sheriff's Departments received several reports of the bridge collapse. Sheriff's deputies from both counties arrived at the bridge at **8:22 p.m.** and discovered that a section of the bridge deck and the supporting column bents had fallen into the river. The deputies closed both ends of the northbound bridge, and from the bridge deck, began to visually search the river with flashlights for victims or survivors. They were able to see one victim and the forward section of a 1978 Pontiac protruding from underneath one of the fallen spans, but did not observe any other victims or vehicles. The deputies made several attempts to reach the collapsed spans; however, due to debris and the depth of the water on the floodplain, they were unsuccessful. The Tennessee Highway Patrol (THP) and Covington Fire Department arrived at the bridge shortly after **8:30 p.m.**, and rescue personnel reached the collapsed spans several minutes later.

An underwater search of the river in the areas of the collapsed spans conducted from April 1 to 4, 1989, revealed that 4 passenger cars and 1 tractor-semitrailer with a total of 8 occupants had plunged into the river. All 8 occupants died as a result of the collapse.

B. **Location** - West Tennessee near Covington. The Hatchie River flows generally east to west toward the Mississippi River.

II. THE BRIDGE

A. Bridge Plan and Profile.

1. Northbound lanes built in 1936, spanned 1,220 m of floodplain on 143 simple spans (nonredundant).

2. Southbound lanes built in 1974, narrowed the bridge opening to 305 m on 13 spans.

B. Piers and Bents (Substructure - 1936 Bridge).

1. Main channel spans supported by reinforced concrete Piers 1 through 7 - about 13.5 m high and 8.0 m long, supported by 29 each 6.1 m long untreated timber piles.

2. Floodplain spans supported by concrete pile bents, 2 each - 8.2 m high columns, 1.2 m caps, 0.9 m footing resting on 5 each 6.1 m untreated friction piles.

3. Generally, about a 4 m difference in elevation of pile caps between main channel piers and shallower floodplain bents.

III. FLOW CONDITIONS (1989)

A. **Bridge designed for 100-year flood** of 2,266 m^3/s with 1.52 m/s main channel velocity. Channel slope was 0.0001 and flow on floodplain was less than 1 m deep with velocity of about 1 m/s.

B. Flow Data.

1. Q_{max} in 1946 = 1,578 m^3/s.

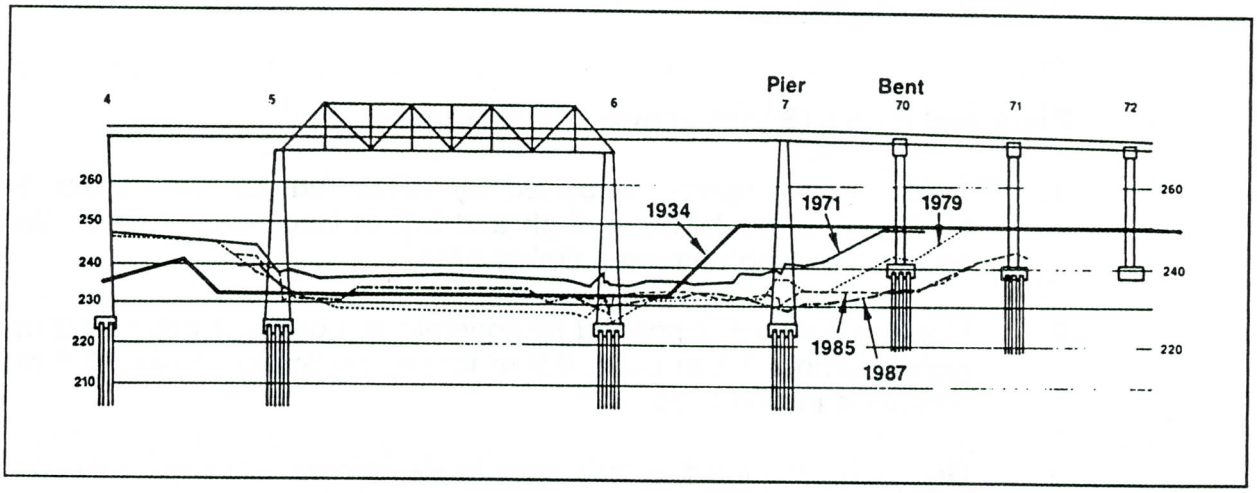
2. Q_{max} on January 19, 1989 = 813 m^3/s (3-year event).

3. Q = 244 m^3/s (2-year event) at time of failure.

4. Duration: The USGS estimated that 1989 was in the top 10 for overbank flow duration and was the most severe since 1974.

C. **Lateral Migration**: a time lapse comparison of cross section shows the following channel migration rates northward toward the floodplain bents:

1931-1975	0.24 m/year (0.8 ft/year)
1975-1989	1.37 m/year (4.5 ft/year)
1981-1989	0.58 m/year (1.9 ft/year)



MIGRATION BASED ON TDOT INFORMATION
(Data Measured at the Northbound Bridge)

D. **Local Scour.**

1. The model constructed at the FHWA Turner-Fairbank Labs showed about 1 m local scour at the floodplain bent that failed.

2. Local scour at the bent was calculated at 1.55 m using the Colorado State University (CSU) equation.

3. Local scour and lateral migration combined to produce about 3 m of exposure on the 6.1 m piles supporting the floodplain bent that failed.

IV. CONCLUSIONS BY THE NATIONAL TRANSPORTATION SAFETY BOARD (1990)

Findings

1. The passenger car drivers and truck driver were unable to avoid the accident.

2. The post-collapse emergency response could not have reduced the severity of this accident.

3. Column bent 71 and span 79 were still standing following the collapse of column bent 70 and spans 77 and 78.

4. The west column of column bent 71 was fractured, and the entire column bent and span 79 subsequently collapsed, as a result of successive impacts from the accident vehicles.

5. The deterioration of the exterior superstructure girders of spans 77, 78 and 79 did not contribute to the bridge collapse.

6. It is unlikely that a fracture of the concrete members of column bent 70 initiated the collapse sequence.

7. It is unlikely that the piles buckled as a result of a reduction in the pile cross sections.

8. Column bent 70 failed most likely from the disembedment of the supporting timber piles, perhaps in combination with pile buckling, due to their exposure from a combination of channel migration and local scour.

9. The simply supported spans of the northbound U.S. 51 bridge allowed the collapse to occur with little warning over a short period of time.

10. It is unlikely that the additional weight of the concrete footings contributed significantly to the collapse.

11. Because of the streambed elevation at the time of the collapse, the rectangular configuration of the footing probably did not affect the depth of local scour.

12. Enough information and guidance was available for the designers of the southbound bridge to have discovered the natural channel meander of the Hatchie River, and to have anticipated that further migration would undermine column bent 70 of the northbound bridge.

13. The on-site **inspections** of the northbound U.S. 51 bridge adequately identified the exposure of the column bent 70 footings and piles because of the northward migration of the Hatchie River channel.

14. Had bridge design or as-built plans been available to the TDOT **inspector** in 1987, he may have discovered that his measurement of the column bent 70 footing was contrary to the designed footing depth.

15. Even though the northbound U.S. 51 bridge did not meet the TDOT criteria to receive a diver **inspection**, a diver **inspection** of the bridge should have been conducted following the 1987 inspection because of the exposure of the timber piles noted in the **inspection** report.

16. The 1987 TDOT **inspection** of the northbound bridge did not occur when conditions were optimum for **inspectors** to examine the substructure bridge elements.

17. Enough guidance and information was available in 1985 and 1987 for TDOT to have recognized the need to develop and study a channel profile record for the Hatchie River at the site of the U.S. 51 bridge.

18. Neither the TDOT regional **inspection** engineer nor the Structures Inventory and Appraisals **evaluator** determined that the undermining of column bent 70 was critical and required immediate action, even though the 1985 and 1987 field **inspection** reports recommended that the column bent be protected from scour.

19. TDOT **evaluators** did not recognize the importance or potential of scour when they reviewed the 1985 and 1987 **inspection** reports.

20. TDOT **evaluators** failed to recognize the potential hazard caused by the exposure of the friction piles supporting column bent 70, even though the information to make this determination was included in the 1987 Bridge **Inspection** report.

21. The frequency with which overweight vehicles were permitted to travel across the bridge was potentially harmful to the structure.

22. Because TDOT did not have sufficient resources to accomplish the majority of the **maintenance** recommendations, they missed the opportunity to correct the channel migration beneath column bent 70, or protect column bent 70 from scour, through **routine preventive maintenance**.

Probable Cause

"The National Transportation Safety Board determines that the probable cause of the collapse of the northbound U.S. Route 51 bridge spans was the northward migration of the main river channel which the Tennessee Department of Transportation failed to evaluate and correct. Contributing to the severity of the accident was the lack of redundancy in the design of the bridge spans."

Recommendations

As a result of its investigation, the National Transportation Safety Board recommends:

--- **To the Federal Highway Administration:**

Modify the National Bridge Inspection Standards to require follow-up or diver inspections of those bridges with underwater members that cannot be examined visually or by feel during scheduled bridge inspections because of excessive water depth or turbidity. (Class II, Priority Action)(H-90-56)

Require States to develop and maintain channel profile records for bridges over water, and to evaluate the channel profile records to determine the effects of channel changes on bridges. (Class II, Priority Action)(H-90-57)

Modify the National Bridge Inspection Standards to require qualifications for personnel who evaluate bridge inspection reports. (Class II, Priority Action)(H-90-58)

Require States to develop a crucial element checklist for each bridge based on the bridge design and as-built plans, or available bridge data. The list should identify bridge elements or conditions that when damaged, exposed, corroded or deformed would independently cause a sudden unexpected collapse of a section of the bridge. This list should then become part of each bridge inspection report. Further, require the States to immediately close the bridge or perform needed repairs when an inspector discovers the deterioration of a bridge element contained in the crucial element checklist. (Class II, Priority Action)(H-90-59)

Require that States review overweight vehicle traffic to evaluate the effects of frequent overweight loads on unposted bridges. Require that, based on these evaluations, the States limit the number or size of overweight vehicles permitted to cross those bridges that may be damaged because of frequent exposure to heavy loads. (Class II, Priority Action)(H-90-61)

--- **To the American Association of State Highway and Transportation Officials:**

Modify Section 1.3.2, "Hydraulic Studies" of the Standard Specification for Highway Bridges to include evaluations of geomorphic changes in streams caused by the construction of a new bridge, and the effects of those changes on existing structures. (Class II, Priority Action)(H-90-61)

Modify Section 2.3, "Frequency and Level of Inspection" of the Manual for Maintenance Inspection of Bridges to include a requirement that bridge inspectors be provided with available bridge design or as-built plans during on-site bridge inspections. (Class II, Priority Action)(H-90-62)

Modify Section 4.6, "Rating of Bridges, Limiting Vehicle Weights" of the Manual for Maintenance Inspection of Bridges to delete the section which exempts certain concrete bridges from load posting. (Class II, Priority Action)(H-90-63)

--- **To the Tennessee Department of Transportation:**

Modify TDOT bridge rating criteria to remove the requirement that a structure show some settlement or leaning before it is rated critical. (Class II, Priority Action)(H-90-64)

Modify bridge inspection procedures to provide inspectors with available bridge design or as-built plans during on-site bridge inspections. (Class II, Priority Action)(H-90-65)

Expand TDOT bridge inspection criteria to require that submerged bridge elements, that cannot be fully examined by bridge inspectors during scheduled inspections, receive follow-up or diver inspections. (Class II, Priority Action)(H-90-66)

Establish an inter-disciplinary team of geotechnical, hydraulic, and structural engineers to develop the repair and rehabilitation programs for those bridges that are determined to be scour-critical. (Class II, Priority Action)(H-90-67)

Immediately repair those bridges determined to have exposed friction piles. (Class II, Priority Action)(H-90-68)

Train TDOT personnel involved in bridge inspections to evaluate scour, in accordance with the FHWA Technical advisory "Scour at Bridges" and other FHWA and AASHTO publications concerning the inspection of underwater bridge elements. (Class II, Priority Action)(H-90-69)

Modify bridge inspection report review procedures to require that hydraulic engineers review and evaluate all bridge inspection reports which identify the presence of scour or channel migration; and emphasize the identification and correction of channel movements and scour. (Class II, Priority Action)(H-90-70)

Obtain weight per axle and axle spacing information for overweight vehicles when issuing overweight permits. (Class II, Priority Action)(H-90-71)

Establish a priority ranking system for maintenance recommendations issued as the result of bridge inspections. (Class II, Priority Action)(H-90-72)

To the State of Tennessee:

Provide Maintenance resource necessary to complete recommended repairs developed as a result of bridge inspections. (Class II, Priority Action)(H-90-73)

As a result of its investigation of this accident, the National Transportation Safety Board reiterates Safety Recommendation H-89-72 to the American Association of State Highway and Transportation Officials:

Modify Section 4.5 "Rating of Bridges, Evaluations" of the Manual for Maintenance Inspection of Bridges to require the evaluation of substructural bridge members during load rating calculations. (H-89-72)

LESSON 4

SCOUR AT HIGHWAY BRIDGES

CONCEPTS AND DEFINITIONS

OVERVIEW: Method of instruction: Lecture

Lesson Length: 30 minutes

Resources:

Lesson 4 Outline
Slides
Video - Colorado State University
HEC-18 Chapters 1, 2, 3

OBJECTIVES: At the conclusion of this lesson, the Participant shall be able to:

1. **Understand** the magnitude and nature of the scour problem.

2. **Understand** the scour problem is four-fold.

3. **Define** the nature of the scour process as a sediment continuity problem.

4. **Define** the three components of scour.

5. **Define** the following:

   - Scour
   - Clear-water scour
   - Live-bed scour
   - Maximum depth of scour
   - Equilibrium scour
   - Aggradation
   - Degradation
   - Contraction scour
   - Local scour
   - Total scour
   - Lateral scour or erosion

LESSON 4

SCOUR AT HIGHWAY BRIDGES

CONCEPTS AND DEFINITIONS

I. SCOUR PROBLEM

A. The United States is Losing Bridges from Scour.

1. 1965 - Colorado lost 63 bridges

2. In 1973, FHWA study of 383 bridge failures found the failures were 25% pier and 75% abutment damage.

3. In 1978, more extensive study showed failures were about 50% pier and 50% abutment damage.

4. 1985 - Pennsylvania, Virginia, and West Virginia lost 73 bridges.

5. 1987 - New York and New England states lost 17 bridges.

6. April 1987 - the Schoharie Creek bridge failure cost 10 lives when 4 cars and a truck went off the bridge.

7. April 1989 - Covington, Tennessee, Hatchie River bridge failure cost 8 lives.

8. In 1990, South Carolina had 72 bridges damaged by floods.

9. 1993 - From information currently available, the flood in the Upper Mississippi basin caused 23 bridge failures for an estimated damage of $15 million. The modes of bridge failure were 14 from abutment scour, 2 from pier scour only, 3 from pier and abutment scour, 2 from lateral bank migration, 1 from debris load, and 1 from unknown scour.

10. 1994 - Flooding from storm Alberto in Georgia, damaged over 500 state and locally owned bridges with scour. Thirty-one of state-owned bridges experienced from 15 to 20 feet of contraction scour and/or long-term degradation in addition to local scour. These bridges had to

be replaced. The state also recommended that 73 other bridges be repaired (shored-up) or replaced of more than 150 identified as scour damaged. Total damage to the highway system was approximately $130 million.

11. 1995 - Several bridges in California fail, including the I-5 bridges over Arroyo Pasajero, resulting in 7 deaths.

12. 60% of all bridge failures are from hydraulic or stream stability problems.

B. **American Association of State Highway and Transportation Officials** (AASHTO) standard specifications for highway bridges has the following requirements to address the problem of stream stability and scour.

1. Hydraulic studies are a necessary part of the preliminary design of a bridge and should include....estimated scour depths at piers and abutments of proposed structures.

2. The probable depth of scour shall be determined by subsurface exploration and hydraulic studies. Refer to Article 1.3.2 and FHWA HEC-18 for general guidance regarding hydraulic studies and design.

3. ....in all cases, the pile length shall be determined such that the design structural load may be safely supported entirely below the probable scour depth.

C. Solution to Scour Problem is Four-Fold.

1. Design of new and replacement bridges.

2. Assessment of scour vulnerable bridges.

3. Inspection of existing bridges.

4. Countermeasures to protect existing bridges.

D. Problem of Existing Bridges Caused by:

1. Most bridges 20 to 40 years old.

2. Design based on inadequate scour knowledge.
   a. Research only since 1950s.
   b. Lack of field data on scour depths and related hydraulic variables.
   c. Lack of fundamental research to improve equations.
3. Many state and local bridges over water.
   a. Piers and/or abutments in flow.
   b. Spread footing or shallow piles.
   c. Overconfidence about rock resistance to scour.
4. Inadequate bridge management systems.
   a. Poor data on existing bridges.
   b. Unknown foundations.
5. Lack of trained personnel.
   a. Hydraulics, river mechanics, etc.
   b. For design, inspection, and evaluation.

II. VIDEO

A short (12 minute) video prepared by Colorado State University will illustrate many of the basic concepts.

III. DEFINITION OF SCOUR

A. Scour.

1. Scour is the result of the erosive action of flowing water, excavating and carrying away material from the bed and banks of streams. Different materials scour at different rates. Loose granular soils are rapidly eroded by flowing water, while cohesive or cemented soils are more scour resistant. However, **ultimate** scour in cohesive or cemented soils can be as deep as scour in sand-bed streams.

2. Scour is a sediment transport problem.

3. Sediment continuity.

Change in Sediment = Sediment Inflow - Sediment Outflow

4. **All** materials erode - it's just a matter of time.

5. Scour occurs when bed material transport at the bridge crossing, or at piers and abutments is larger than incoming bed material transport (supply).

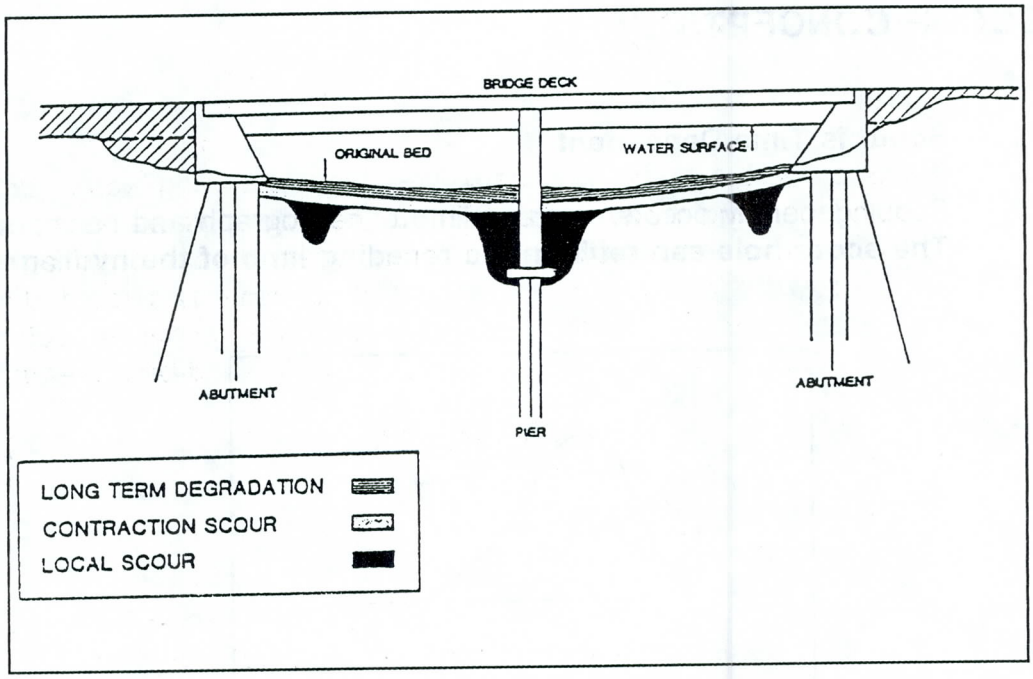
B. Scour Components.

1. Long-term aggradation or degradation.

2. Contraction scour.

3. Local scour.

C. **Total Scour** - Normally considered the sum of the three components. Error not large unless local scour holes overlap.

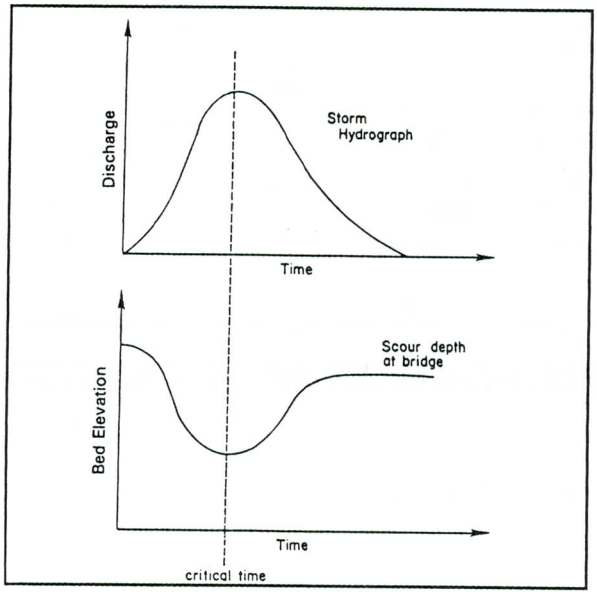


DEFINITION SKETCH - TOTAL SCOUR

IV. SCOUR CONCEPTS

A. Scour is Time Dependent.

Scour generally occurs on rising limb of hydrograph and near peak flow. **The scour hole can refill on the receding limb of the hydrograph.**



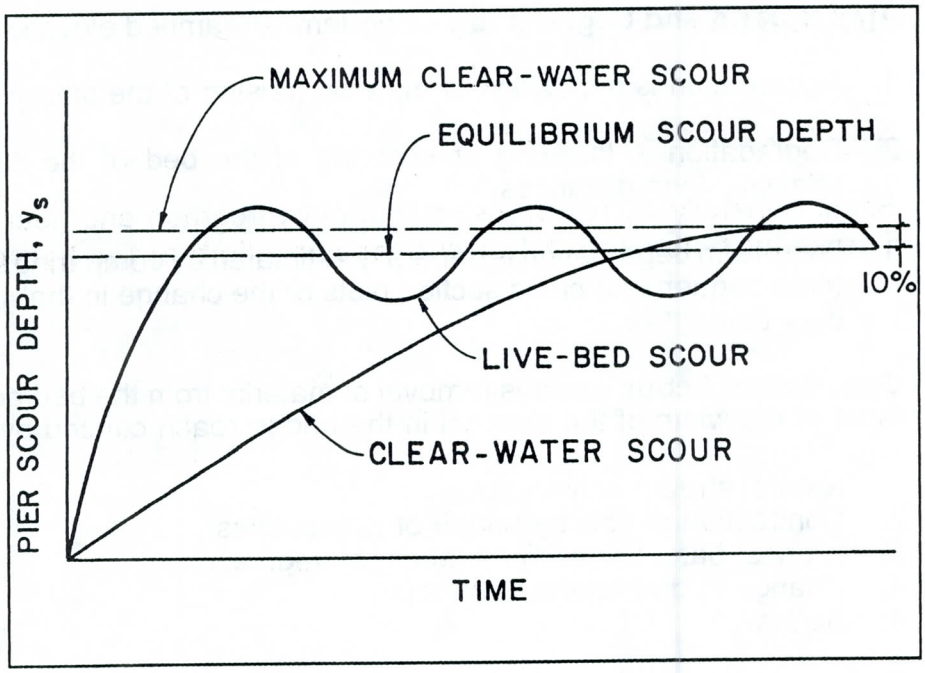
TEMPORAL CHANGE OF SCOUR HOLE DEPTH DURING A STORM

B. Types of Scour.

There are two types of bridge scour: clear-water and live-bed.

1. **Live-bed scour** occurs when the bed material in the channel upstream of the bridge is moving at the flow causing bridge scour.

2. **Clear-water scour** occurs when the bed material in the channel upstream of the bridge is not moving at the flow causing bridge scour. (This does not imply fine sediment could not be in motion as wash load.)



PIER SCOUR DEPTH AS A FUNCTION OF TIME (SCHEMATIC)

3. Clear-water scour occurs mainly on coarse-bed streams, or on well vegetated floodplain overbank areas.

4. Maximum clear-water pier scour about 10% greater than equilibrium live-bed pier scour.

5. Conditions can be such that at low-flow scour would be clear-water, but at high-flow scour would be live-bed.

C. Equilibrium Depth of Pier Scour.

1. Live-bed scour in a sand-bed stream with a dune bed fluctuates about an equilibrium scour depth due to variability in the bed material transport in the approach flow, as dune bedforms move through the bridge reach.

2. The recommended equations for local scour estimate maximum scour depths.

D. **Aggradation and Degradation** - long-term streambed elevation changes.

1. Aggradation is deposition of material (raising of the streambed).

2. Degradation is lowering or scouring of the bed of the stream over relatively long distances.

3. Long-term degradation is generally estimated by comparing successive (time-sequenced) cross section plots or the change in thalweg profiles over time.

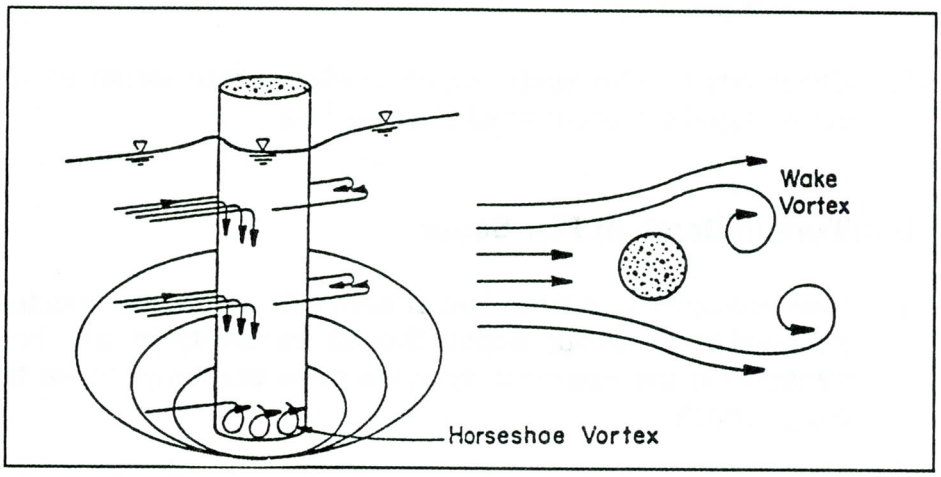
E. **Contraction Scour** involves removal of material from the bed across all or most of the width of the channel in the bridge reach caused by:

1. Natural stream constrictions.
2. Contraction of flow by bridge or approaches.
3. Islands, bars, berms, ice, debris, or vegetation.
4. Change in downstream control.
5. Bends.

F. **Local Scour** involves removal of material restricted to a minor part of width of channel, at an obstruction.

1. Local scour occurs at obstructions in the flow, such as piers, abutments, spurs, and embankments.

2. Caused by acceleration of the flow and development of vortex systems induced by obstructions in the flow.



SCHEMATIC REPRESENTATION OF LOCAL SCOUR AT A CYLINDRICAL PIER

G. **Total Scour** is generally the sum of aggradation or degradation, contraction scour, and local scour.

H. **Lateral Shifting of Stream** may erode approach roadway or change total scour by changing approach angle of the flow at the bridge.

1. Bridges are static, rivers are dynamic (see Lesson 2).

2. Must evaluate vulnerability of bridge to changes in planform (lateral channel migration).

NOTES:

LESSON 5

SCOUR PROCESSES - CONTRACTION, PIER, AND ABUTMENT SCOUR

OVERVIEW: Method of Instruction: Lecture

Lesson Length: 45 minutes

Resources:

Lesson 5 Outline
Slides
HEC-18 Chapter 4

OBJECTIVES: At the conclusion of this lesson, the Participant shall be able to:

1. **Understand** contraction scour processes.
2. **Understand** pier scour processes.
3. **Understand** abutment scour processes.

LESSON 5

SCOUR PROCESSES - CONTRACTION, PIER, AND ABUTMENT SCOUR

I. CONTRACTION SCOUR

A. Contraction Scour - Occurs when the flow area of a stream at flood stage is reduced, either by a natural contraction or by a bridge.

B. Contraction Scour is Typically Cyclic - That is, the bed scours during the rising stage of a runoff event, and fills on the falling stage.

C. Other Factors that can Cause Contraction Scour are:

1. natural stream constrictions,
2. long highway approaches over the floodplain to the bridge,
3. ice formation or jams,
4. natural berms along the banks due to sediment deposits,
5. island or bar formations upstream or downstream of the bridge,
6. debris,
7. growth of vegetation in the channel or floodplain.

D. There are Two Approaches for Estimating Contraction Scour: One for Live-Bed and One for Clear-Water Scour.

1. For any case or condition, it is only necessary to determine if the flow in the main channel or overbank is transporting bed material **(live-bed scour)** or is not **(clear-water scour)**. The appropriate equation is then applied with the variables defined according to the location of the contraction scour being analyzed (channel or overbank). HEC-18 provides criteria for selecting the appropriate equation.

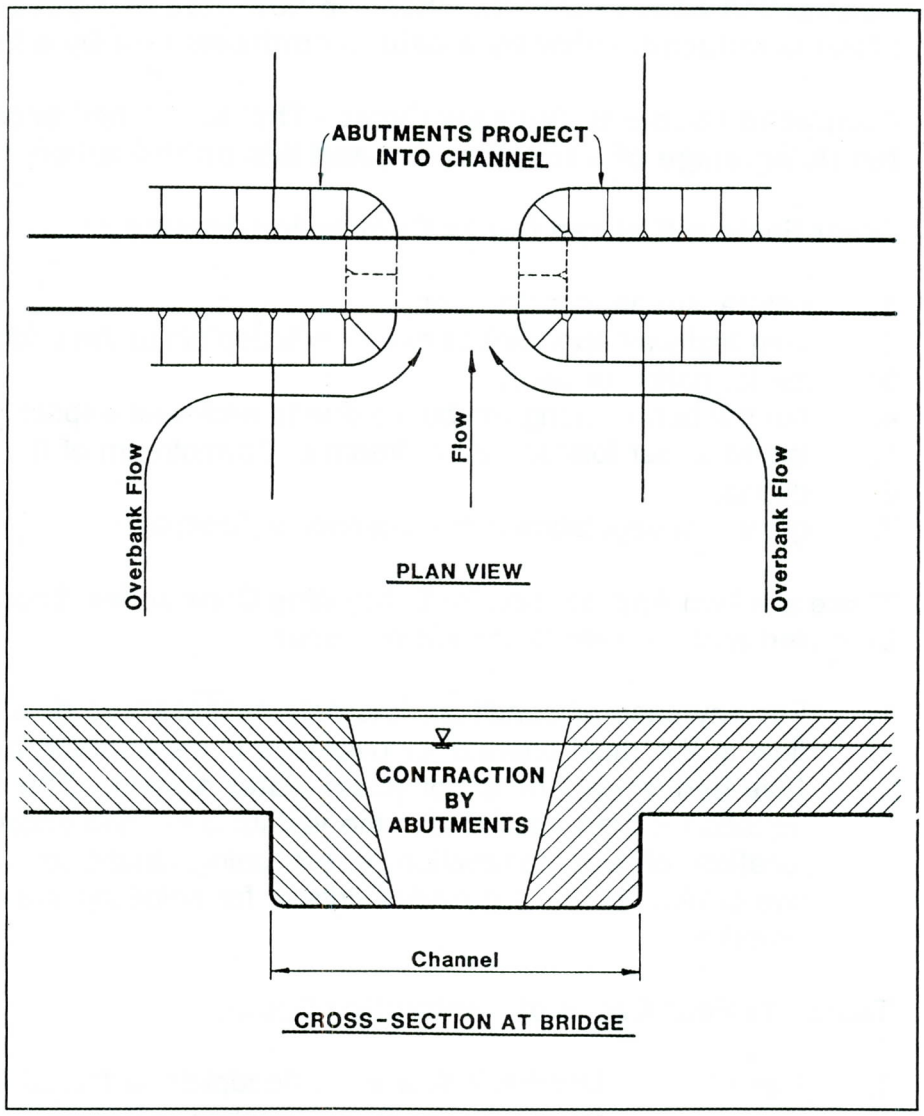
E. There are Four Cases of Contraction Scour.

1. Case 1. Overbank flow on a floodplain is forced back to the main channel by approaches to bridge.

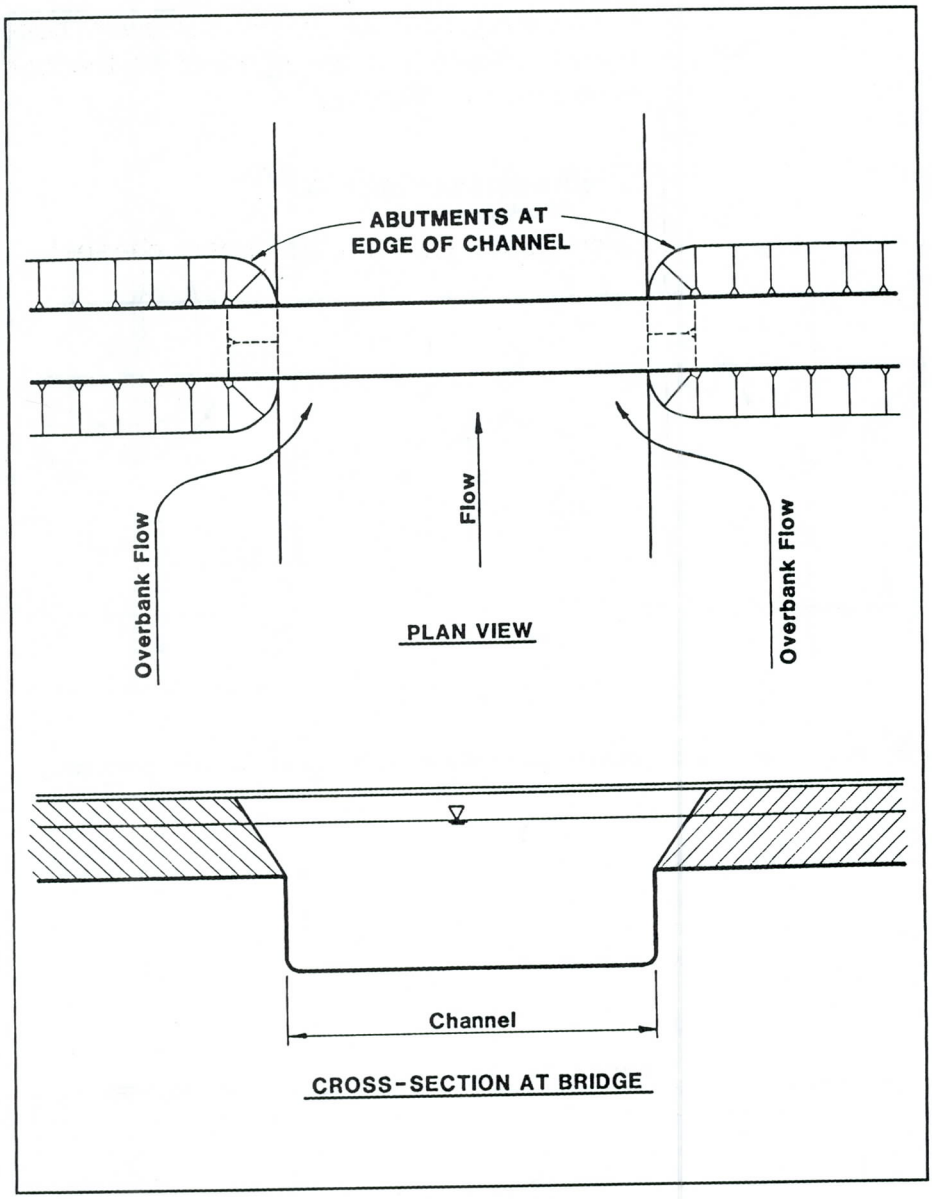
a. River channel width becomes narrower because bridge abutments project into the channel or the bridge is on a narrower reach of the river.

b. Abutments set at the streambank.

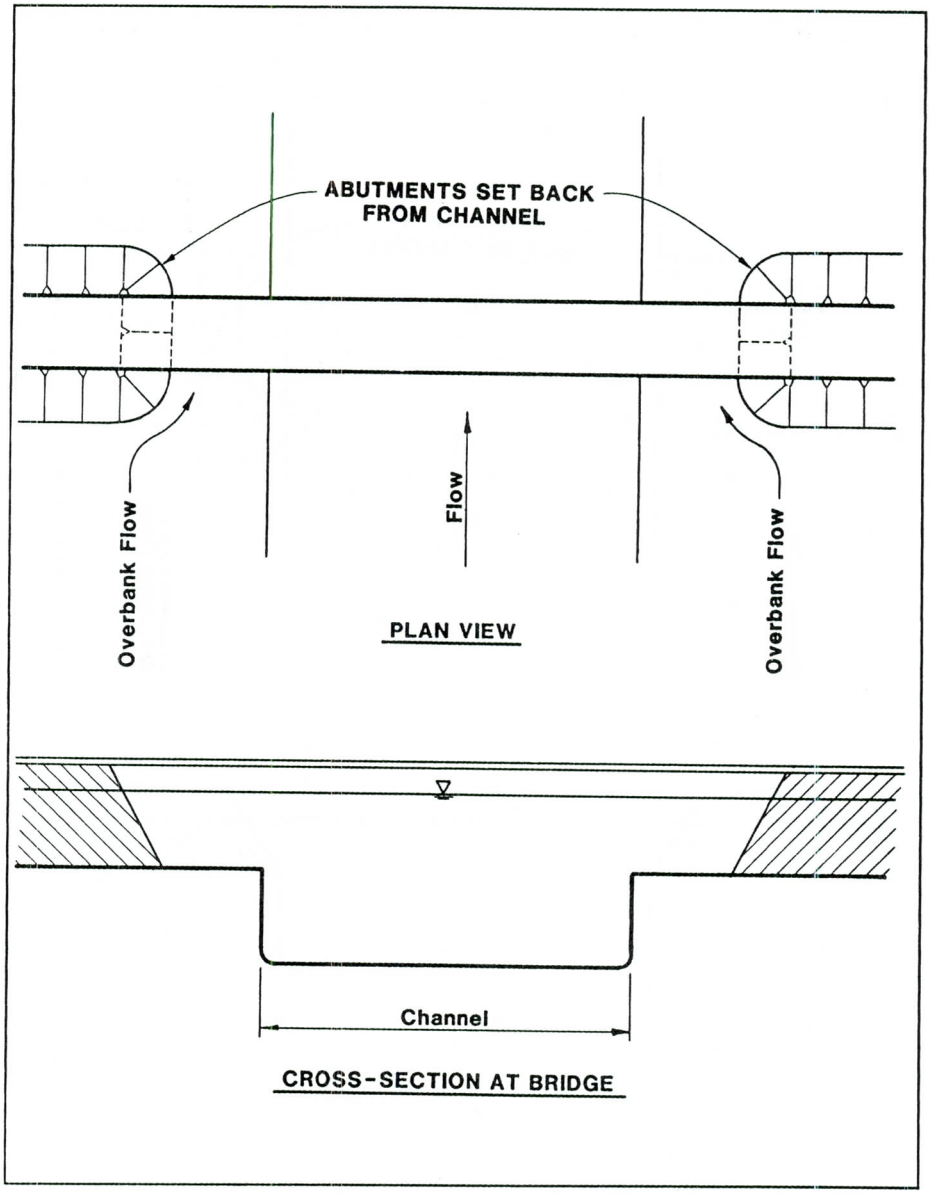
c. Abutments set back from the stream channel.



CASE 1A: ABUTMENTS PROJECT INTO CHANNEL



CASE 1B: ABUTMENTS AT EDGE OF CHANNEL



CASE 1C: ABUTMENTS SET BACK FROM CHANNEL

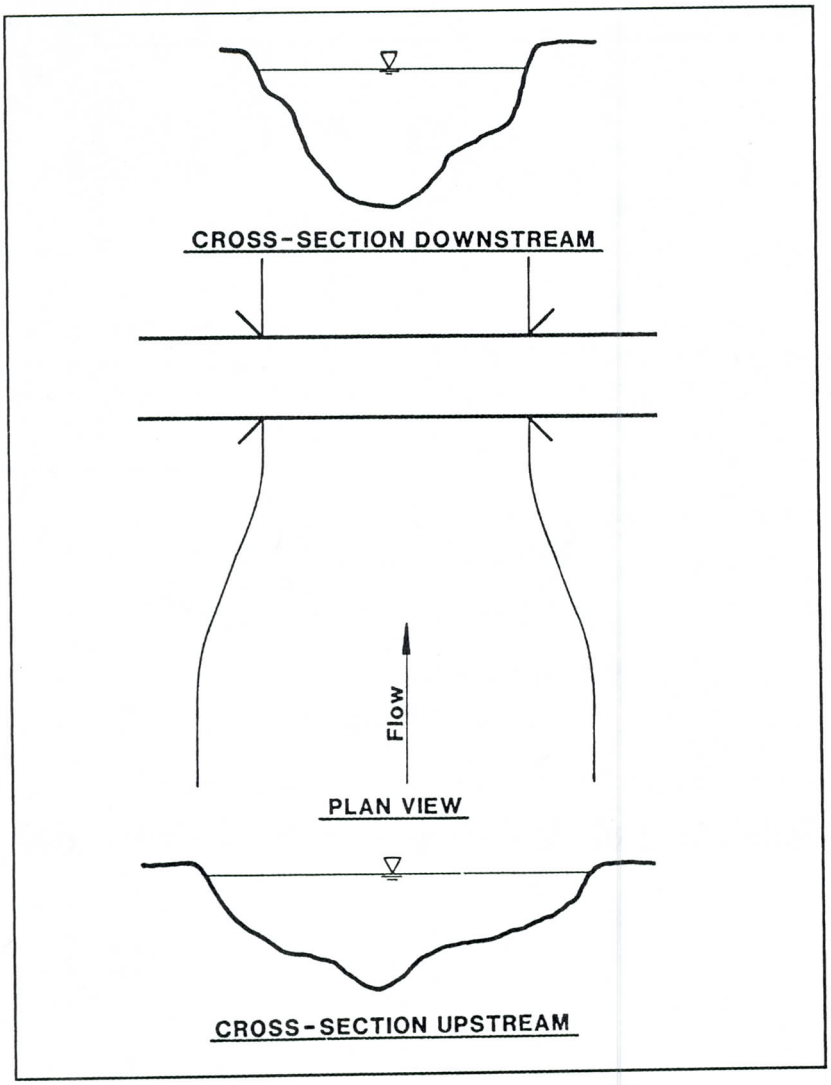
2. Case 2. No overbank flow.

   a. The bridge site is on a narrower reach of river.

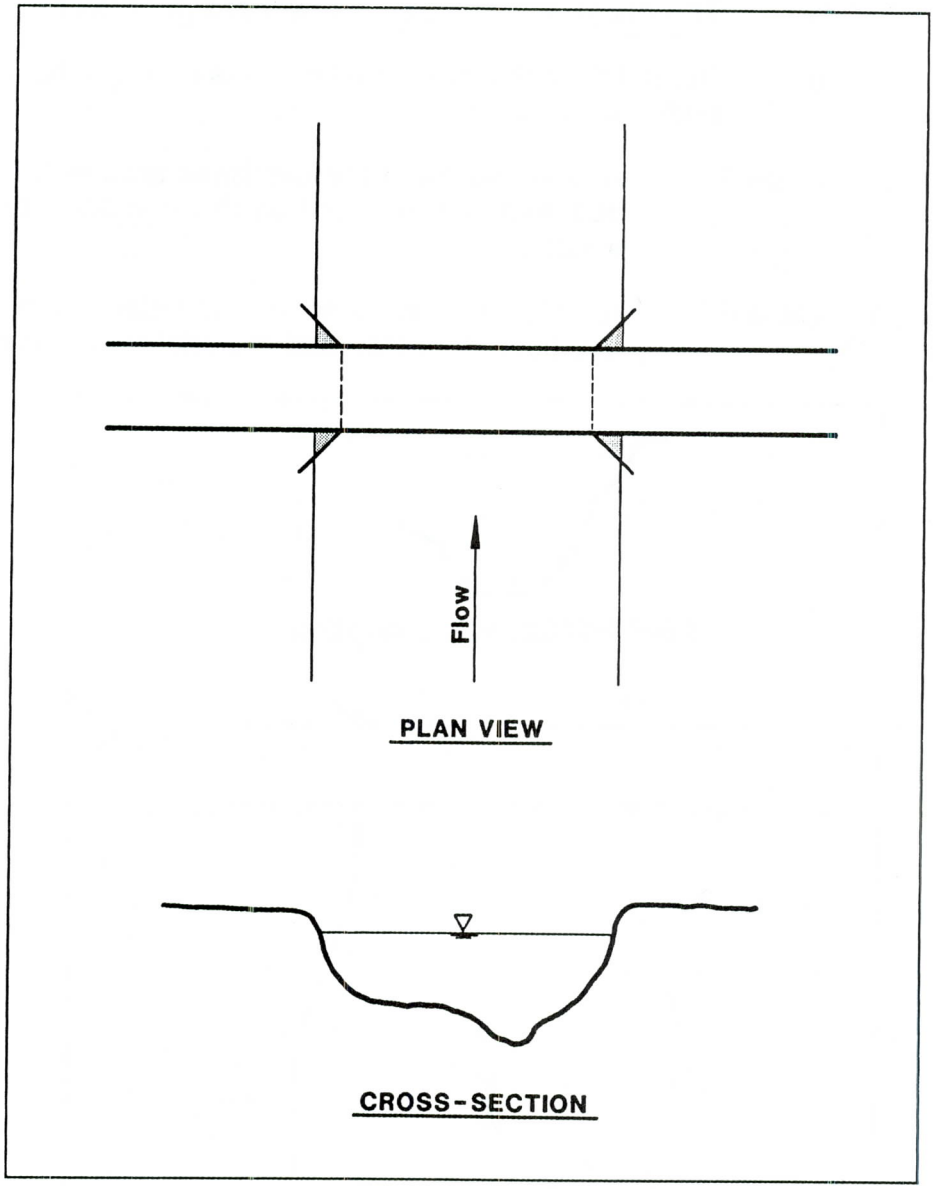
   b. Normal river channel width becomes narrower because of the bridge itself.

3. Case 3. A relief bridge in the overbank area with little or no bed material transport in the overbank area (clear-water).

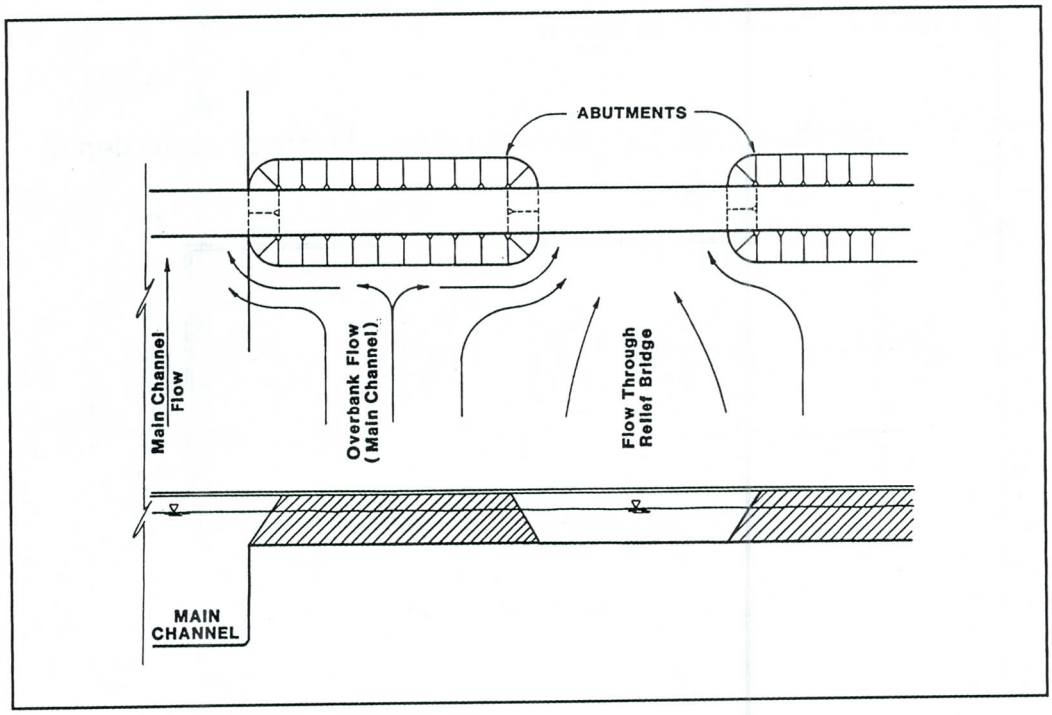
4. Case 4. A relief bridge over a secondary stream in the overbank area with bed material transport (live-bed).



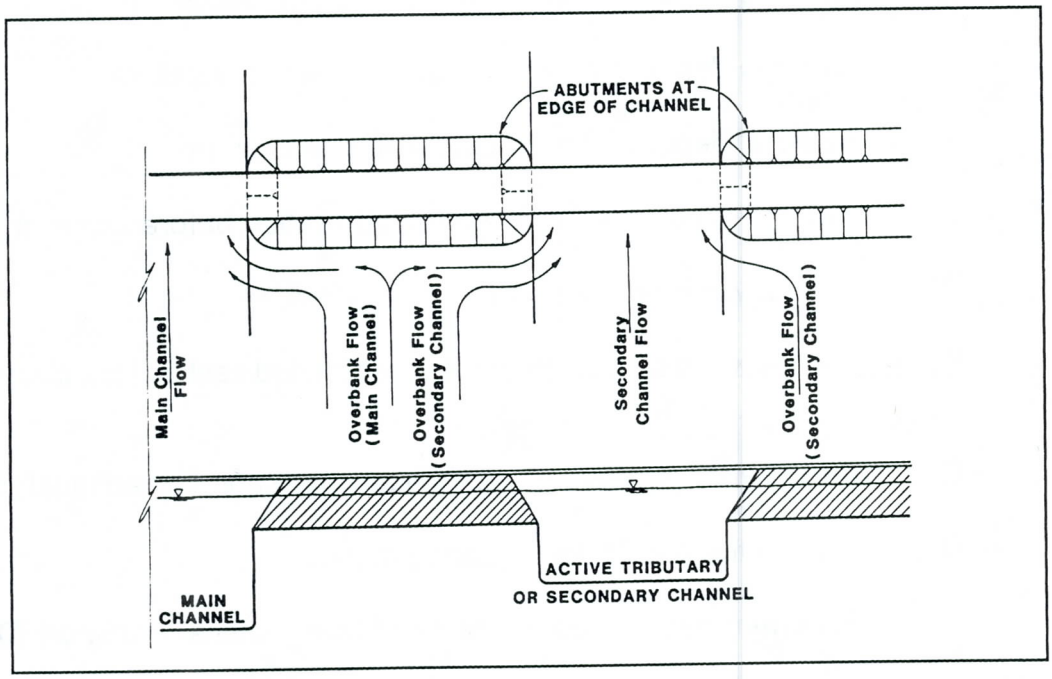
CASE 2A: RIVER NARROWS



CASE 2B: BRIDGE ABUTMENTS CONSTRICT FLOW



CASE 3. RELIEF BRIDGE OVER FLOODPLAIN



CASE 4. RELIEF BRIDGE OVER SECONDARY STREAM

F. Live-bed Contraction Scour.

1. Modified 1960 Laursen's equation: (average scour depth)

$$\frac{y_2}{y_1} = \left[\frac{Q_2}{Q_1}\right]^{\frac{6}{7}} \left[\frac{W_1}{W_2}\right]^{k_1}$$

average scour depth $y_s = y_2 - y_0$

where

y_s = Average depth of scour in the contracted section, m

y_1 = Average depth of flow in upstream main channel, m

y_2 = Average depth of flow in contracted section, m

y_0 = Existing depth of flow in contracted section before scour, m

W_1 = Bottom width of upstream main channel, m

W_2 = Bottom width of main channel in contracted section less pier widths, m

Q_1 = Flow in the upstream channel that is transporting sediment, m^3/sec

Q_2 = Flow in the contracted channel, m^3/sec

k_1 = Exponent determined by mode of bed material transport (0.59 to 0.69)

2. **Qualitatively, this equation tells us that live-bed contraction scour <u>increases</u> if:**

   a. **The total flow in the contracted section (Q_2) is much greater than the upstream (main channel) flow (Q_1).**

   b. **The channel width in the contraction (W_2) is much smaller than the uncontracted channel width upstream (W_1).**

G. **Clear-water Contraction Scour.**

1. A recommended clear-water contraction scour equation is:

$$\boxed{y_2 = \left(\frac{0.025\ Q^2}{D_m^{\frac{2}{3}}\ W^2} \right)^{\frac{3}{7}}}$$

$$y_s = y_2 - y_0$$

where

y_0 = Existing depth of flow in the contracted section before scour, m

y_2 = Average depth of flow in the contracted section after contraction scour, m

y_s = Depth of scour in the contracted section, m

Q = Discharge through the bridge or on the overbank at the bridge associated with the width, W, m^3/sec

D_m = $1.25\ D_{50}$, m

D_{50} = Median diameter of bed material, m

W = Bottom width of the contracted section less pier widths, m

2. **Qualitatively, this equation tells us that clear-water contraction scour <u>increases</u> if:**

   a. **The discharge in a clear-water channel or on the overbank at the bridge is large.**

   b. **The channel width or overbank width is small.**

   Clear-water contraction scour <u>decreases</u> as the bed material particle size gets larger.

G. Tips for Inspecting for Contraction Scour.

1. Sand-bed channels normally have live-bed scour.

2. Clear-water scour occurs mainly on coarse-bed channels or on well vegetated floodplain areas.

3. Significant contraction scour can occur if the total upstream flow is captured by roadway approach embankments and forced through the bridge opening.

4. Flow through relief bridges or over roadway approach embankments can reduce the flow and contraction scour in the main channel bridge opening.

5. Q_1 is the flow in the main channel upstream of the bridge (not including overbank flows).

6. The average width of the bridge opening (W_2) is generally taken as the bottom width, with the width of the piers subtracted.

7. Where abutments are set back from the main channel, the contraction scour in the main channel may be occurring under live-bed conditions, while the contraction scour in the setback overbank area can be clear-water scour.

8. If there is no overbank flow, $Q_2 = Q_1$ and only a change in channel width will influence live-bed contraction scour.

9. Unusual conditions will require knowledge of river mechanics and analysis by experienced engineers.

NOTES:

II. PIER SCOUR

A. Pier Scour Mechanism.

1. Recall from Lesson 4 that any obstruction in the flow, such as a pier, creates a horseshoe vortex around the front and sides of the obstruction.

2. The wake vortex behind the pier moves material that is eroded from the front and sides of the pier downstream.

3. Like contraction scour, pier scour is typically cyclic. The pier scour hole is generally deepest near the peak of a runoff event, and fills on the falling stage.

4. Pier scour is influenced by many variables, including flow characteristics, pier geometry, footing geometry and elevation, and bed material.

B. Pier Scour Variables.

1. Flow characteristics.

   a. V_1, Velocity upstream of the pier.

   b. Y_1, Depth of flow upstream of the pier.

   c. Angle of attack of the flow.

   d. Pressure flow.

2. Pier geometry.

   a. Pier width.

   b. Pier length.

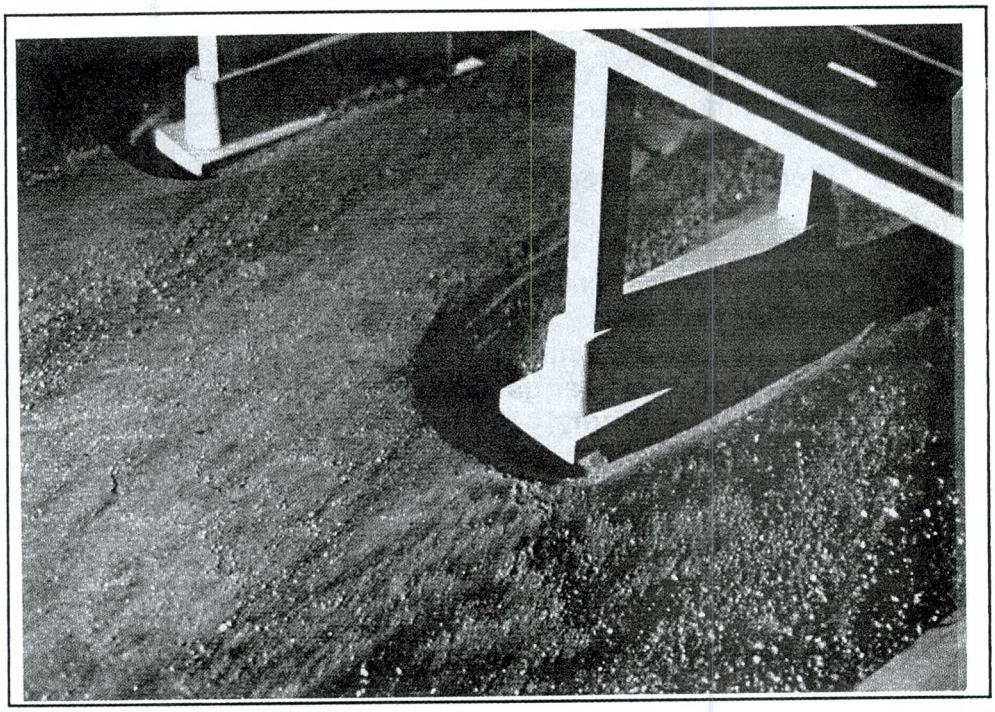
   c. Pier shape.

3. Footing geometry and elevation.

   a. Width.
   b. Length.
   c. Thickness.
   d. Elevation with respect to the bed surface.

4. Bed material.

   a. Size.
   b. Gradation.
   c. Cohesiveness.
   d. Stratification.
   e. Bed configuration.



SCOUR HOLES - HYDRAULIC MODEL OF SCHOHARIE CREEK BRIDGE

C. Types of Pier Scour.

1. **Live-bed scour** occurs when the bed material upstream of the crossing is moving.

2. **Clear-water scour** occurs when there is no movement of the bed material of the stream upstream of the crossing, but the acceleration of the flow and vortices created by the piers or abutments cause the material at their base to move.

   - **Clear-water scour** occurs mainly on coarse-bed streams or on well-vegetated floodplain overbank areas. Maximum clear-water pier scour is about 10% greater than equilibrium live-bed scour.

   - **Bridges** over coarse bed material streams often have clear-water scour at the lower part of a hydrograph, live-bed scour at the higher discharges, and then clear-water scour on the falling stages.

D. Estimating Pier Scour.

1. Recommended equation.

   Pier scour has been studied extensively in the laboratory, but there is only limited field data. As a result of the many studies, there are many equations. In general, the equations are for live-bed scour in cohesionless sand-bed streams.

   For the determination of pier scour, the modified Colorado State University (CSU) equation is recommended for both live-bed and clear-water scour.

   For plane-bed and antidune flow, the CSU equation gives a scour depth about 10% less than maximum scour.

2. The modified CSU equation for pier scour.

   The modified CSU equation is:

$$y_s = 1.224\ K_1\ K_2\ K_3\ K_4\ a^{0.65}\ V_1^{0.43}\ y_1^{0.135}$$

where

y_s = Scour depth, m
K_1 = Correction for pier shape from figure and table
K_2 = Correction for angle of attack of flow from table
K_3 = Correction for bed condition from table
K_4 = Correction factor for armoring of the scour hole
a = Pier width, m
V_1 = Mean velocity directly upstream of the pier, m/s
y_1 = Flow depth directly upstream of the pier, m

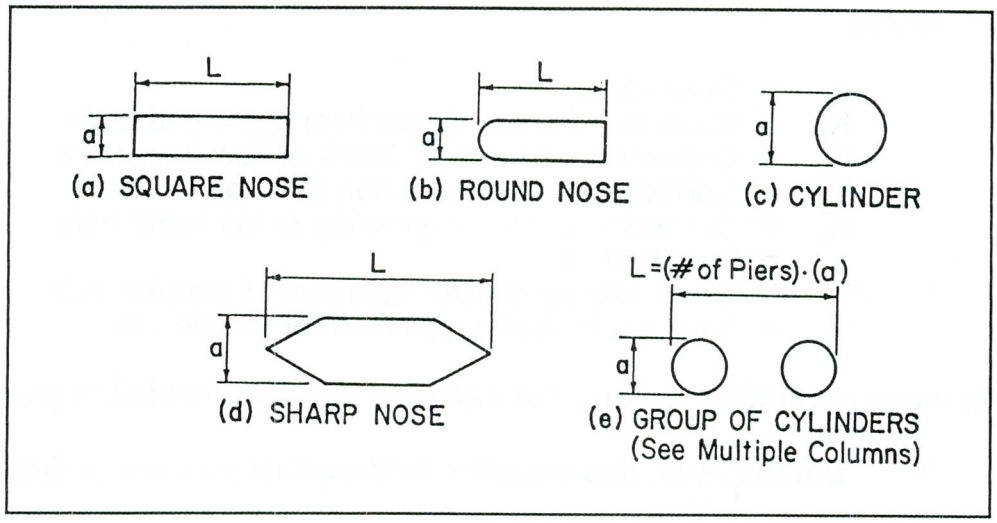
With these correction factors, the equation predicts maximum pier scour.

3. **Qualitatively, this equation tells us that pier scour <u>increases</u> if:**

   a. **Pier has a blunt, rather than streamlined shape**
   b. **Flow approaches a long web pier at a large angle of attack**
   c. **Bed consists of large dunes**
   d. **Pier width is large**
   e. **Velocity is large**
   f. **Flow depth is large**

4. The correction factor for pier nose shape, K_1, should be used for angles of attack up to 5 degrees. For greater angles, the correction factor for angle of attack dominates, pier nose shape loses its effect and K_1 should be considered as 1.0. For K_2, if L/a is greater than 12, use the L/a = 12 values as a maximum.

Correction Factor, K_1 for Pier Type		Correction Factor, K_2 for Angle of Attack of the Flow			
Type of Pier	K_1	Angle	L/a = 4	L/a = 8	L/a = 12
(a) Square nose	1.1	0	1.0	1.00	1.0
(b) Round nose	1.0	15	1.5	2.00	2.5
(c) Circular cylinder	1.0	30	2.0	2.75	3.5
(d) Sharp nose	0.9	45	2.3	3.30	4.3
(e) Group of cylinders	1.0	90	2.5	3.90	5.0
		Angle - skew angle of flow L = length of pier			



COMMON PIER SHAPES

5. The bed condition correction factor, K_3, can be estimated from the following table:

Bed Condition	Dune Height H (m)	K_3
Clear-water Scour	NA	1.1
Plane bed and antidune flow	NA	1.1
Small Dunes	$3 > H \geq 0.6$	1.1
Medium Dunes	$9 > H \geq 3$	1.1 to 1.2
Large Dunes	$H \geq 9$	1.3

6. The correction factor, K_4, decreases the calculated depth of scour in cohesionless materials if coarse material ($D_{50} \geq 0.06$m) is present in the scour hole. The correction factor ranges from 1.0 for no armoring to 0.70 for very coarse material.

7. A **Rule of Thumb** for estimating pier scour.

Available research suggests for round nose piers aligned with the flow, the maximum value of the ratio of scour depth to pier width (y_s/a) should be taken as 2.4 for tranquil flow and 3.0 for rapid flow.

Thus, as a Rule of Thumb, the maximum depth of a pier scour hole can be estimated at between 2.4 and 3.0 times the pier width. This estimate is valid only for round nose piers aligned with the flow.

E. Pier Scour for Exposed Pile Groups.

Pile groups that project above the streambed can be analyzed conservatively by representing them as a single pier width equal to the projected area of the piles ignoring the clear space between piles. Good judgment needs to be used in accounting for debris because pile groups tend to collect debris that could effectively clog the clear spaces between piles and cause the pile group to act as a much larger mass.

F. Pier Scour with Pressure Flow.

Pressure flow occurs when the water surface elevation at the upstream face of the bridge is greater than or equal to the low chord of the bridge superstructure.

Pressure flow under the bridge results from a pile-up of water on the upstream bridge face, and a plunging of the flow downward and under the bridge. At higher approach flow depths, the bridge can be entirely submerged with the resulting flow being a complex combination of the plunging flow under the bridge and flow over the bridge.

With pressure flow, the local scour depths at a pier or abutment are larger than for free surface flow with similar depths and approach velocities. Laboratory studies of pressure flow scour indicate that pier scour can be increased 200% to 300% by pressure flow.

G. Debris.

Debris (trees, brush, trash) or ice accumulating on a bridge pier can increase the depth of scour significantly.

H. Width of Scour Holes.

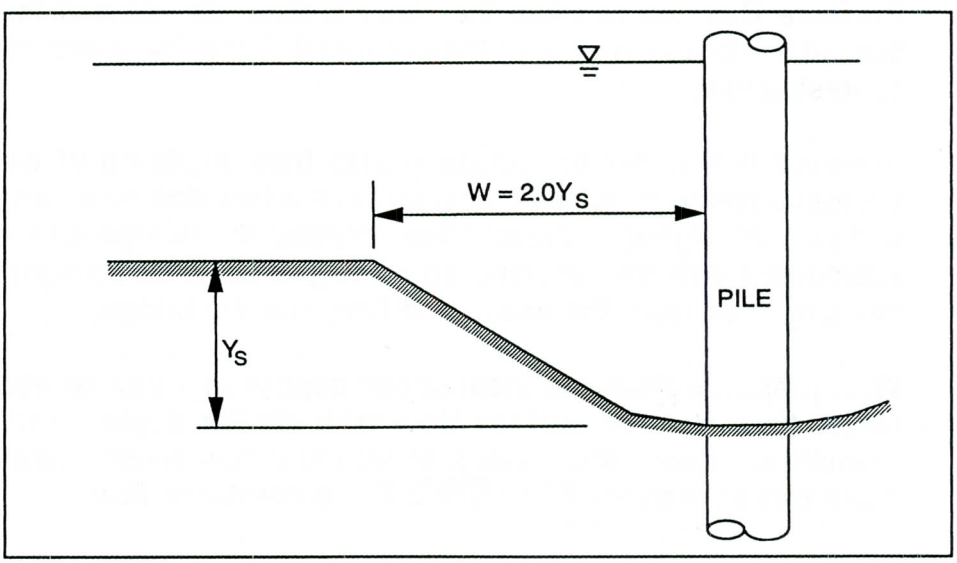
The top width of a scour hole in cohesionless bed material from one side of a pier or footing can be estimated as from 1.0 to 2.8 times the depth of scour. For practical applications use:

$$W = 2.0\ y_s$$

where

W = Top width of scour hole from one side of pier, as shown in the following figure, m

y_s = Scour depth, m



ESTIMATED WIDTH OF A SCOUR HOLE

I. Tips for Inspecting for Pier Scour.

1. Width of pier has a direct effect on the depth of scour.

   An increase in pier width means an increase in scour depth.

2. Length of a pier has no appreciable effect on scour depth if the pier is aligned with the flow.

   If the pier is at an angle to the flow, the length has a very large effect on the depth of the scour hole. **Doubling the length of the pier can increase the scour depth from 30% to 60% (depending on the angle of attack).**

3. Flow depth has a direct effect on scour depth.

   An increase in flow depth can increase scour depth by a factor of 2 or more.

4. Velocity of the approach flow increases scour depth.

   The larger the velocity, the deeper the scour depth.

5. Pressure flow.

   When bridge deck is submerged, scour depth increases.

6. **Size of the bed material in the <u>sand size range</u> has no effect on scour depth.**

   Fine bed material (silts and clays) will have scour depths as deep as sand-bed streams (even if bonded by cohesion). The effect of cohesion is to influence the time it takes to reach the maximum scour.

   With sand-bed material, the maximum depth of scour is measured in hours. With cohesive bed materials, it may take days, months, or even years to reach the maximum scour depth.

   Coarser bed material can limit the depth of scour.

7. Angle of attack of the flow to the pier has a large effect on local scour (see pier length).

8. **Shape of pier has a significant effect on scour.** Streamlining the front end reduces the strength of the horseshoe vortex reducing scour depth. Streamlining the downstream end reduces the strength of the wake vortices.

   A square-nose pier will have maximum scour depths about 20% larger than a sharp-nose pier and 10% larger than a cylinder or round-nose pier.

   The shape of the pier nose has no effect on the magnitude of the scour when the angle of attack is greater than about 5 degrees.

9. Bed configuration affects the magnitude of local scour.

10. Ice and debris can increase the width of the piers, change the shape of piers, and cause the flow to plunge downward against the bed and increase pier scour.

    Debris can be taken into account in the scour equations by estimating how much the debris will increase the width of the pier.

III. ABUTMENT SCOUR

A. Abutment Scour Mechanism.

1. At the upstream end of the abutment, the scour mechanism is the horseshoe vortex (similar to that which occurs at a pier).

2. At the downstream end of the abutment, flow can separate from the boundary and another vortex can form (similar to the wake vortex with piers) and attack the approach roadway embankment.

3. Abutment scour can be live-bed or clear-water.

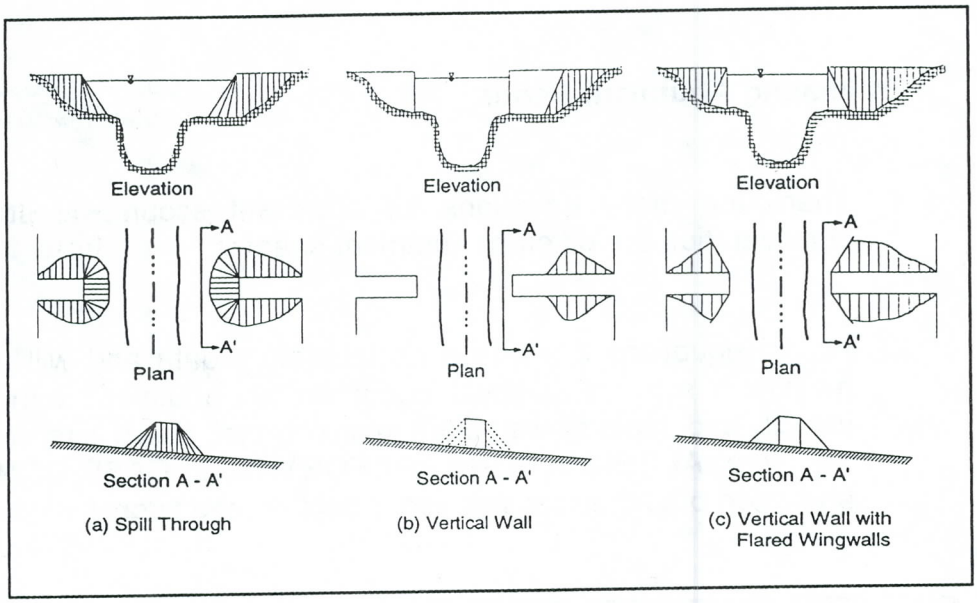
B. Abutment Site Conditions.

1. Abutment shape - three general shapes for abutments:

   a. Spill-through abutments.

   b. Vertical wall abutments without wing walls.

c. Vertical wall abutments with flared wing walls.



COMMON SHAPES OF ABUTMENTS

2. Abutment locations - abutments may:

   a. Project into the channel.

   b. Be at the edge of the channel.

   c. Be set back from channel.

3. Flow may be overbank or confined to channel. Overbank flow returning to the channel at the abutment increases scour depths because:

   a. Returning flow increases the strength of vortices.

   b. Typically, the returning flow is sediment free.

4. Abutments at or back from the edge of the channel may have less scour than abutments that project into the flow because:

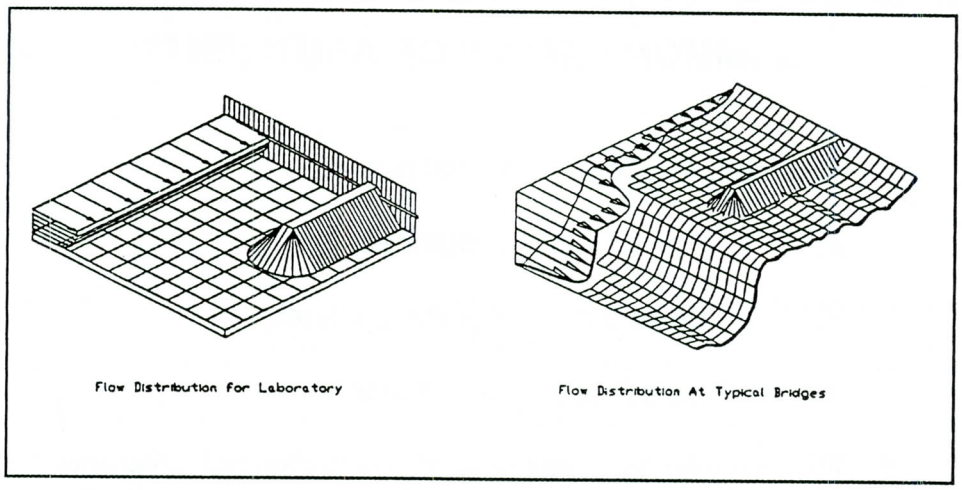
   a. Bankline may have trees or brush which decrease the flow velocity and are resistant to scour.

b. The abutment is out of the main flow and the velocities and depth will be smaller.

C. Estimating Abutment Scour.

1. There are many equations for abutment scour. Most take into consideration the different abutment shapes.

2. All the equations are based on laboratory data and will predict the maximum scour that could occur for an abutment with approach velocity and depth similar to the main channel, which is rarely the case; therefore, **ALL EQUATIONS ARE FOR WORST CASE, CONDITIONS**, and often predict excessive scour depths (see figure).



COMPARISON OF LABORATORY FLOW CHARACTERISTICS TO FIELD CONDITIONS

3. **Froehlich's (1989) equation.**

Froehlich (1989) analyzed 170 live-bed scour measurements in laboratory flumes to obtain the following equation:

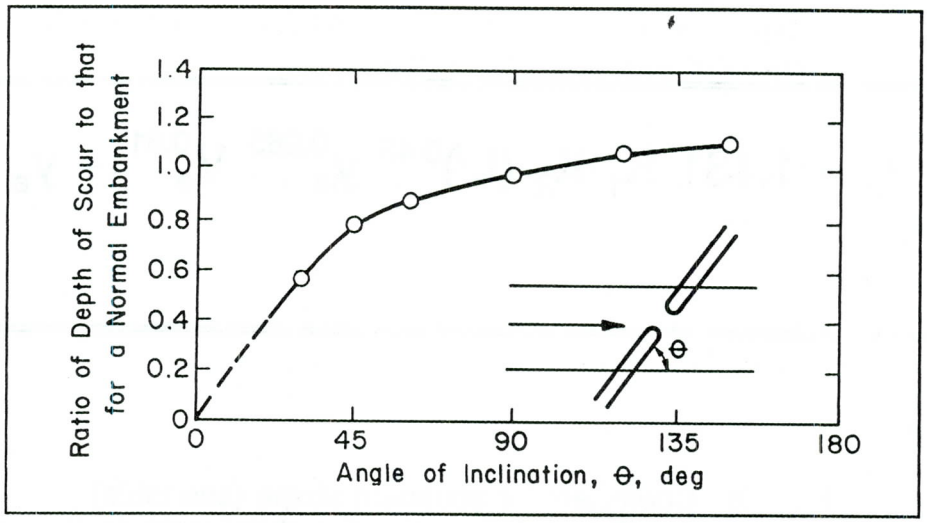
$$y_s = 1.131\ K_1\ K_2\ (L')^{0.43}\ y_a^{0.265}\ V_e^{0.61} + y_a$$

where

K_1 = Coefficient for abutment shape (see table)
K_2 = Coefficient for angle of embankment to flow (see figure)
L' = Length of abutment (embankment) projected normal to flow, m
V_e = Velocity of approach flow upstream of the abutment, m/s
y_a = Average depth of flow on floodplain, m
y_s = Scour depth, m

Abutment Shape Coefficients.	
Description	K_1
Vertical-wall abutment	1.00
Vertical-wall abutment with wing walls	0.82
Spill-through abutment	0.55

To correct the abutment scour equation for abutments skewed to the stream, (K_2), use the following figure



CORRECTION FACTOR FOR SKEWED ABUTMENTS

4. **Qualitatively, this equation tells us that abutment scour <u>increases</u> if:**

   a. **A long approach embankment intercepts overbank flow**

   b. **The depth of flow upstream of the abutment is large**

   c. **The velocity of flow approaching the abutment is high**

   d. **The abutment is angled (skewed) upstream into the flow**

   Note that vertical wall abutments will have twice the scour depths of spill-through abutments.

D. Tips for Inspecting for Abutment Scour.

1. The potential for **lateral channel migration, long-term degradation, and contraction scour** should be considered when inspecting for abutment scour.

2. **Riprap and guide banks** can be used to protect an abutment from failure.

3. **Riprap** or some other bank protection should always be used to protect the abutment from lateral erosion or channel migration.

4. **Abutment scour** will be most severe where the approach roadway embankment leading to the abutment obstructs a significant amount of overbank flow.

5. **Scour** can also occur at the downstream end of the abutment as the flow expands through the bridge opening.

6. **Abutment scour will increase** if the abutment (embankment) is skewed in an upstream direction (into the flow) as shown in the skew correction figure.

7. **Abutment scour will decrease** if the abutment (embankment) is skewed in a downstream direction (away from the flow).

8. **Remember, a vertical wall abutment will have twice the scour depth as a spill-through (sloping) abutment**.

LESSON 6

STREAM INSTABILITY AND SCOUR COUNTERMEASURES

OVERVIEW: Method of Instruction: Lecture

Lesson Length: 30 minutes

Resources:

Lesson 6 Outline
Slides
HEC-20, Chapters 5 and 6
HEC-18, Chapter 7

OBJECTIVES: At the conclusion of this lesson, the Participant shall be able to:

1. **Recognize** countermeasures for:

   a. Meander migration.
   b. Channel braiding and anabranching.
   c. Long-term aggradation and degradation.
   d. Contraction and local scour.

2. **Describe** scour countermeasures for new and existing bridges.

3. **Explain** why riprap is only a temporary countermeasure to protect an existing bridge from pier scour.

4. **Recognize** well-designed riprap.

LESSON 6

STREAM INSTABILITY AND SCOUR COUNTERMEASURES

I. PURPOSE OF COUNTERMEASURES

A. A **countermeasure** controls, inhibits, changes, delays, or minimizes stream instability problems.

B. Countermeasures can be either **integral** or **appurtenant** to the bridge.

C. **Retrofitting** for countermeasures sometimes makes good economic sense.

D. **Monitoring** is also considered a countermeasure.

II. FACTORS AFFECTING PERFORMANCE OF COUNTERMEASURES

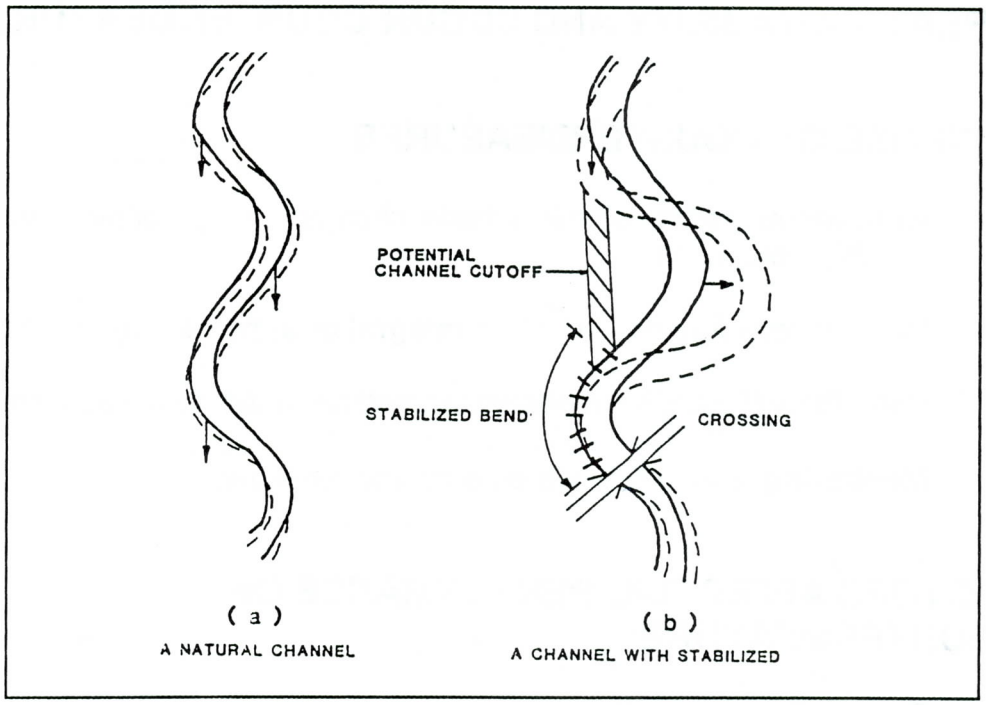
A. Stream Characteristics.

1. Channel width.
2. Bank height.
3. Bank vegetation.
4. Sediment transport.
5. Bend radii.
6. Velocities and flow depths.
7. Ice and debris.
8. Flow on floodplain.

B. Construction and Maintenance Requirements.

1. A poorly designed countermeasure can just make the problem worse.
2. A countermeasure needs to be inspected and maintained frequently.

III. COUNTERMEASURES FOR LATERAL CHANNEL MIGRATION



MEANDER MIGRATION AND COUNTERMEASURES

A. Locate Bridge on Straight Reach.

1. Protect existing banks.

2. Establish new alignment. (Yes, a limited cut off program can work--with sound engineering and consideration of potential consequences!)

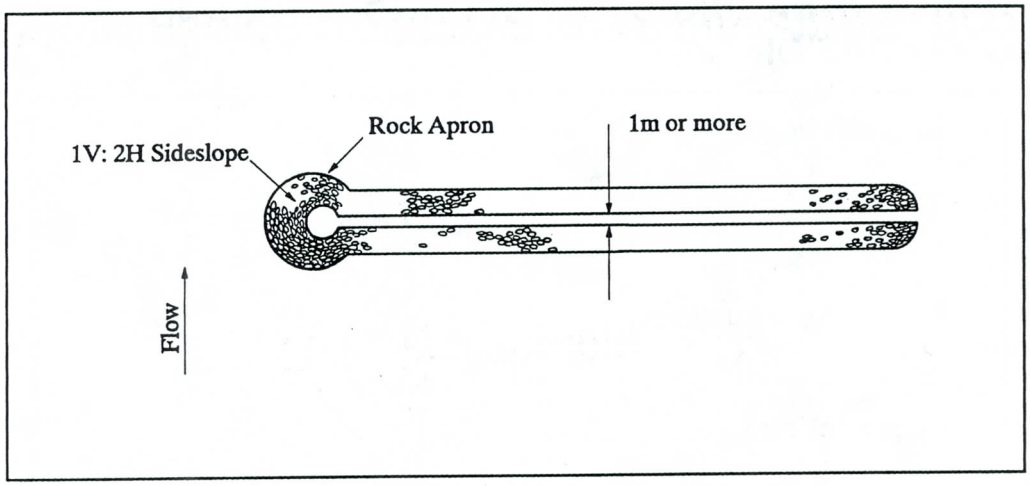
3. Control and constrict channel flow.

B. Countermeasure Methods Include:

1. Spurs.

   - Impermeable.

   - Permeable.



TYPICAL ROUND NOSE SPUR

2. Revetments.

3. Retardance structures, longitudinal dikes.

4. Jack field.

5. Channel relocation.

IV. COUNTERMEASURES FOR CHANNEL BRAIDING AND ANABRANCHING

A. Confine Multiple Channels by:

1. Spur fields.

2. Dikes.

3. Multiple bridge crossings.

V. COUNTERMEASURES FOR DEGRADATION AND AGGRADATION

A. Degradation.

1. Check dams.

2. Drop structures.

B. Aggradation.

1. Maintenance is the most important countermeasure for aggrading bridge crossings, including:

   a. Channelization.

   b. Bridge modifications.

   c. Continued dredging.

   d. Controlled sand and gravel mining. (Yes, sand and gravel can be considered a renewable resource, with sound engineering and a consideration of potential consequences!)

VI. CASE HISTORIES OF STREAM INSTABILITY COUNTERMEASURES

Section 5.7 of HEC-20 summarizes case histories of stream instability problems at bridge sites and provides information on the success (or failure) of various countermeasures used to stabilize streams. This information is from a study of 224 bridge sites in North America as reported in Report No. FHWA-RD-78-163 and is recommended reading.

VIII. COUNTERMEASURES FOR SCOUR AT BRIDGES

A. General.

1. New bridges.

a. Locate bridge to avoid adverse flood flow patterns.

b. Minimize bridge obstructions to flow.

c. Design foundations safe from scour.

- Piers should be founded sufficiently deep to not require riprap or other countermeasures.
- Abutments can be founded above the estimated scour depth when the abutment is protected by well designed riprap or other suitable countermeasures.

2. Existing bridges.

a. Evaluate for vulnerability.

b. Monitor and inspect.

c. Flood watch and close if necessary.

d. Replace.

e. Construct countermeasures.

f. Plan of action. (See Chapter 7, HEC-18, and Lesson 7 for discussion of monitoring inspecting, and closing scour critical bridges.)

B. Contraction Scour.

1. Stabilization of the bed and banks is not a recommended countermeasure.

2. Countermeasures should reduce flow contraction or the effects of contraction.

   a. Increase flow area at the bridge opening:

      - Raise the bridge.
      - Widen bridge opening.
      - Increase spacing of piers.

   b. Decrease discharge flowing through bridge opening:

      - Relief bridges.
      - Overtopping approaches.

   c. Retard flow returning to bridge opening:

      - Spurs.
      - Guide banks (spur dikes).

C. Local Scour.

1. Countermeasures should reduce scour depth or move scour away from structural elements of the bridge.

2. Countermeasures for **abutment scour**.

   a. Guide banks (spur dikes).

   b. Revetments.

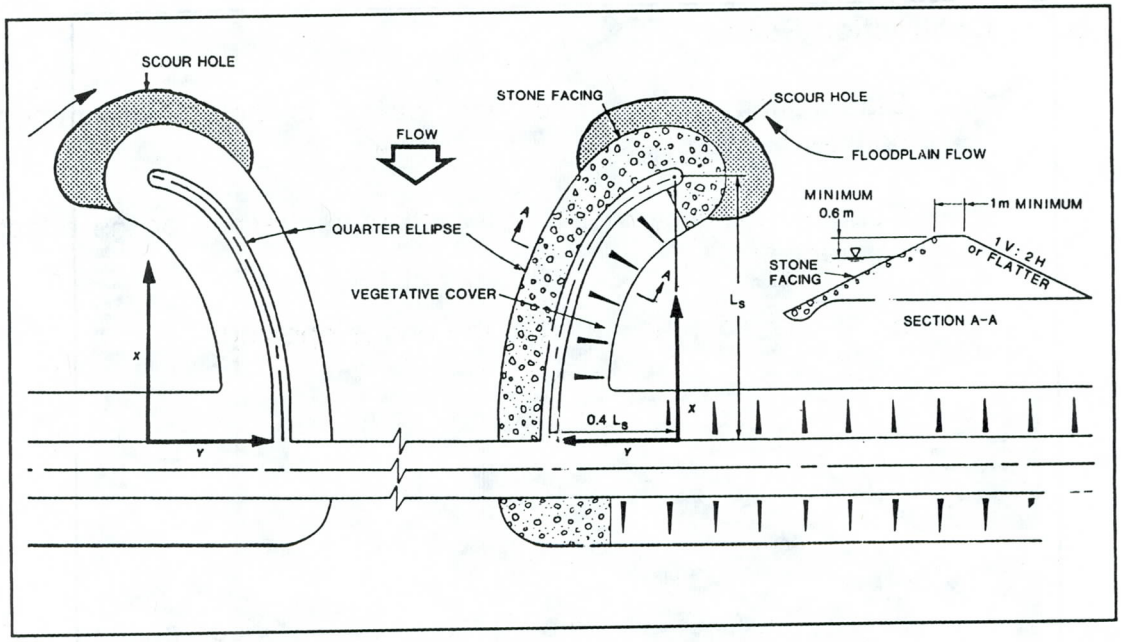


DIAGRAM OF GUIDE BANK

3. Guide bank functions.

   a. Cut off overland flow returning to the main channel.

   b. Guide flow through bridge opening.

   c. Transfer scour away from bridge abutments.

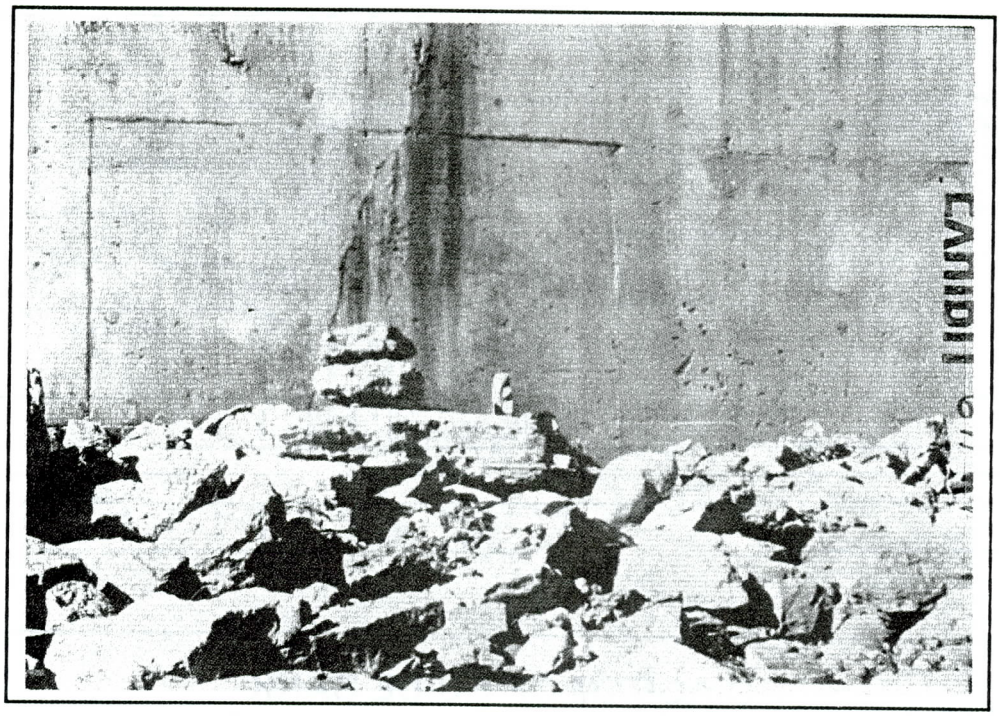
   d. Prevent erosion of approach embankments.

4. Countermeasures at **piers**.

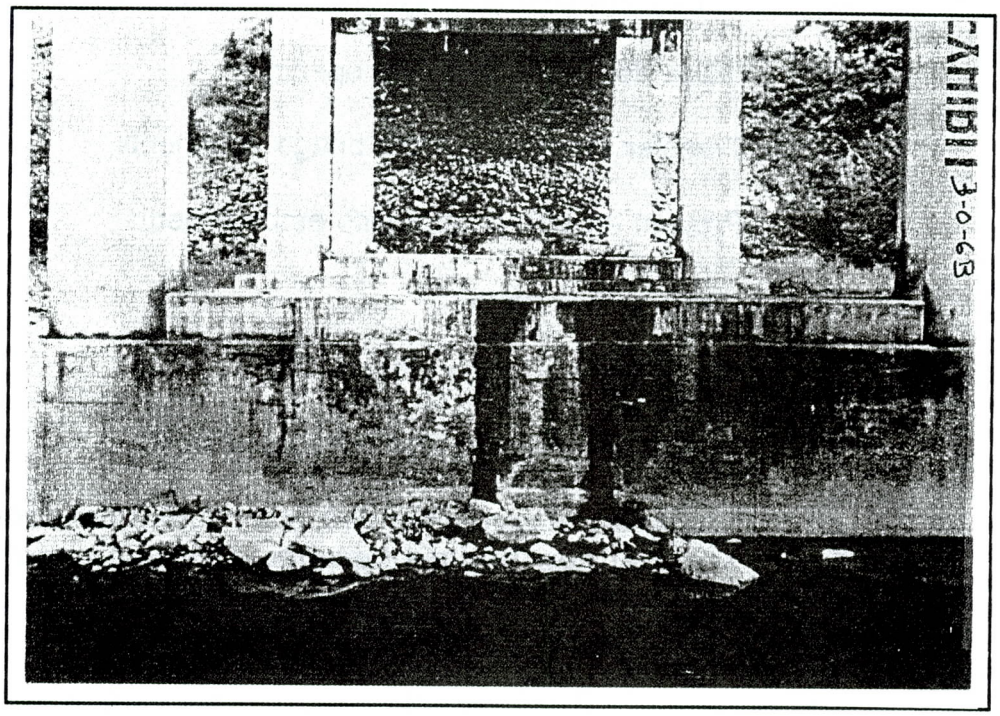
   a. Streamline and align piers to flow.

   b. Increase spacing of piers and columns.

   c. **Riprap is not recommended as a countermeasure for pier scour at new bridges because it can be removed over time** (see photos).

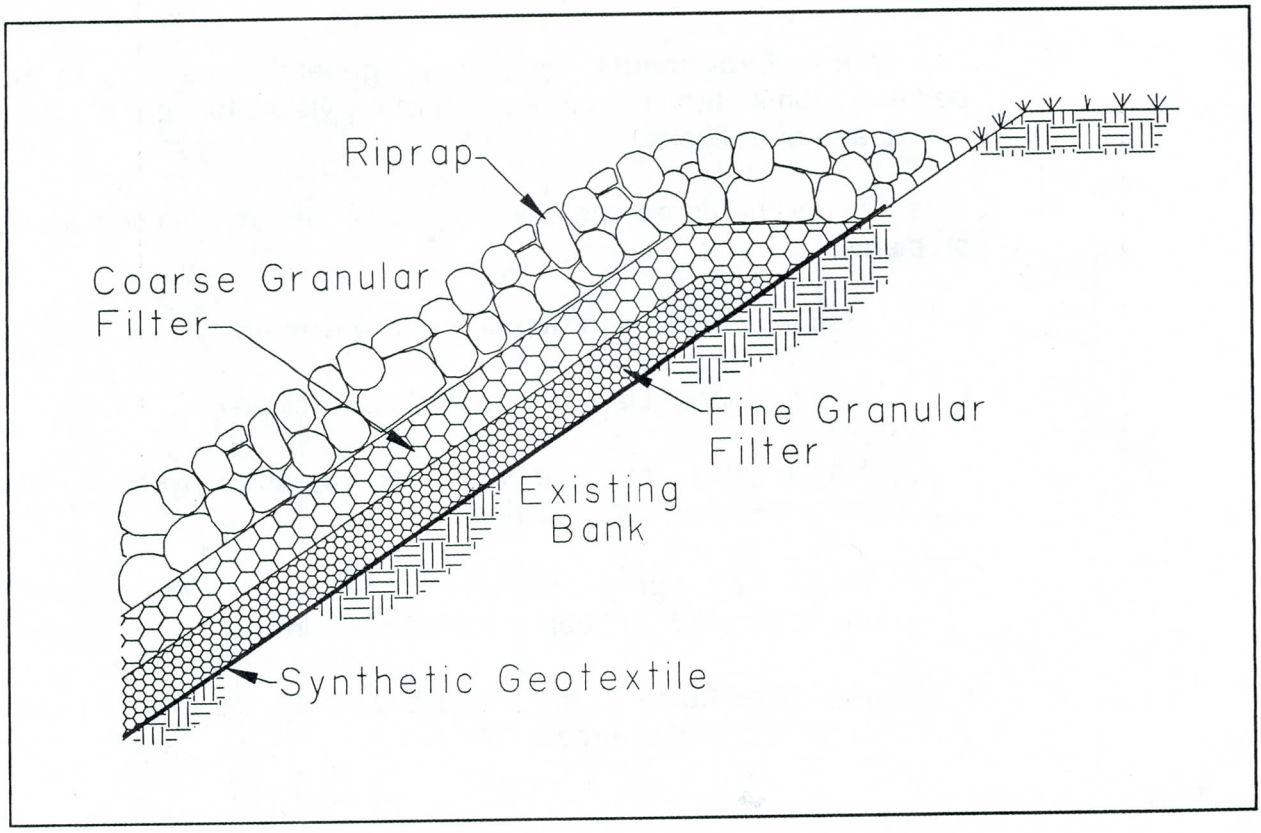


Riprap at Pier 2 Schoharie Creek Bridge in 1956



Riprap at Pier 2 Schoharie Creek Bridge in 1977

d. **Riprap can be considered as a temporary countermeasure at existing bridges, but only with monitoring and inspection during and after high flows.**



SCHEMATIC OF RIPRAP AND FILTERS

D. Tips for Inspecting Riprap at Bridges.

1. Riprap should be **angular and interlocking**. (Old bowling balls would <u>not</u> make good riprap). Flat sections of broken concrete paving do not make good riprap.

2. Riprap should have a **granular or synthetic geotextile filter** between the riprap and the embankment to prevent the loss of embankment material.

3. Riprap should be **well graded** (a wide range of rock sizes). The maximum rock size should be no greater than about twice the median (D_{50}) size.

4. **Revetment riprap** must have an adequate burial depth at the toe (toe down) to prevent it from being undercut. Toe down should be deeper than the expected long-term degradation and contraction scour. Additional material should be provided to launch into any scour hole that develops.

5. For **piers and abutments**, riprap should generally extend up to the bed elevation so that the top of the riprap is visible to the inspector, during and after floods.

6. When inspecting riprap, the following would be strong indicators of problems:

   - Has the riprap been **displaced** downstream?
   - Has the riprap blanket **slumped** down slope?
   - Has angular riprap material been **replaced** over time by smoother river run material?
   - Has the riprap material physically **deteriorated, disintegrated**, or been **abraded** over time?
   - Are there **holes** in the riprap blanket where the filter has been exposed or breached?

NOTES:

LESSON 7

NBIS AND CODING FOR STREAM STABILITY AND SCOUR

OVERVIEW: Method of Instruction: Lecture

Lesson Length: 30 minutes

Resources:

Lesson Outline
Slides
HEC-18, Chapter 6
T 5140.23
1988 Recording and Coding Guide

OBJECTIVES: At the conclusion of this lesson, the Participant should:

1. **Understand** how scour and stream stability inspection relates to the National Bridge Inspection Standards (NBIS).

2. **Understand** what is required by Technical Advisory, T 5140.23, dated October 28, 1991.

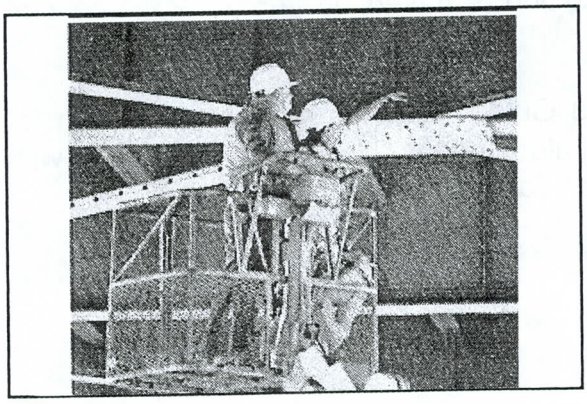
3. **Know** what a scour-critical rating means.

4. **Understand** the relationship between a scour inspection and NBIS coding.

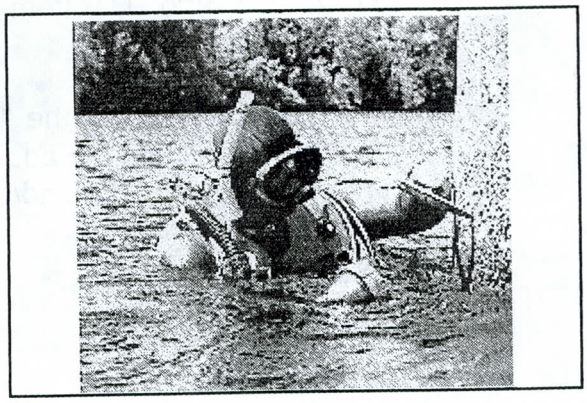
LESSON 7

NBIS AND CODING FOR STREAM STABILITY AND SCOUR

I. NBIS REQUIREMENTS RELATED TO UNDERWATER INSPECTION AND SCOUR



Bridge inspection crew at work



Dive inspection crew at work

A. The **National Bridge Inspection Standards (NBIS)** require that each State Highway Agency shall have a bridge inspection program.

B. Each of the **575,400 bridges in the National Bridge Inventory** shall be inspected at regular intervals not to exceed 2 years. There is a provision for longer periods (4 years) between inspections if justified and approved by the Federal Highway Administration.

C. **Bridges with underwater members** which cannot be visually inspected during periods of low flow or examined by feel for condition, integrity and safe load capacity due to excessive water depth or turbidity shall be inspected by divers at least once every 5 years. Divers inspect for both scour and structural integrity. Underwater inspections are coded in Items 92 and 93 of the Recording and Coding Guide for Structure Inventory and Appraisal of the Nation's Bridges ("Coding Guide").

D. **The "Coding Guide"** involves nearly 100 separate items describing the bridges, about 25 of which are reviewed at each bridge inspection. Items relevant to bridge scour and channel stability are: Item 60, Substructure; Item 61, Channel and Channel Protection; Item 71, Waterway Adequacy (all three included in the original Coding Guide); Items 92 and 93, Critical Feature Inspection (underwater); and Item 113, Scour Critical Bridges (Items 92, 93, and 113 were added in the 1988 revision of the Coding Guide).

E. **The 1987 Schoharie Creek bridge failure** with national press coverage provided impetus for inclusion of bridge scour in the NBIS.

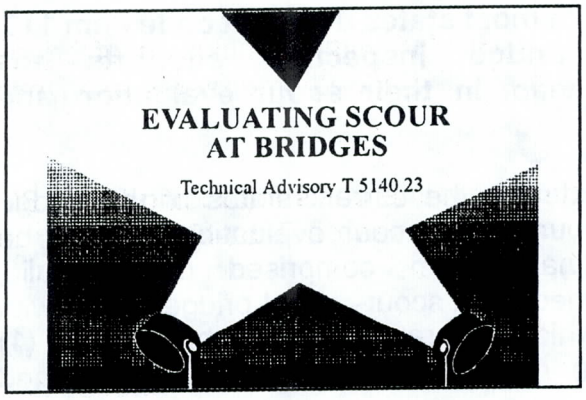
F. **The 1988 revision of the "Coding Guide"** with its inclusion of bridge scour strengthened certain coding items and added other items relative to scour.

G. **The 2-year cycle bridge inspections** are the basis for coding Items 60, 61, 71, 92, and 93. Item 113 coding is based on T 5140.23, Scour at Bridges.

H. The 1996 revision of the "Coding Guide" includes metric conversion for coding bridges and the addition of alpha codes "U" and "T" for bridges with unknown foundations and/or over tidal waterways, respectively.

NOTES:

II. TECHNICAL ADVISORY T 5140.23



Technical Advisory T 5140.23

A. **A National Scour Evaluation Program** as an integral part of the National Bridge Inspection Program was established by Technical Advisory T 5140.20, issued in 1988.

B. **T 5140.23**, issued in 1991 to supersede T 5140.20, provides guidance on the development and implementation of procedures for evaluating bridge scour.

C. The **Technical Advisory** indicates new bridges should be designed for scour by assuming that all streambed material in the computed scour prism has been removed and is not available for bearing or lateral support.

D. The **Technical Advisory** indicates that every existing bridge over a waterway should be evaluated for scour in order to determine if it is scour-critical and to define prudent measures to be taken for its protection.

E. **An Interdisciplinary Team consisting of hydraulic, structural, and geotechnical engineers should conduct the scour evaluations**.

F. **The Scour Evaluations should include the following steps:**

1. Prioritize scour-susceptible bridges.
2. Perform scour analysis.
3. Determine scour-critical bridges.

G. Results of the Evaluation are Coded in Item 113:

Currently, the bridge inspector in most states does not code Item 113, but information from a bridge inspection supports the interdisciplinary engineering team in their scour evaluation and coding of Item 113.

A single digit code is used to identify the current status of the bridge regarding its vulnerability to scour. The scour evaluations should be conducted by an interdisciplinary team comprised of hydraulic, geotechnical, and structural engineers. A scour-critical bridge is one with abutment or pier foundations which are rated as unstable due to (1) observed scour at the bridge site, or (2) a scour potential as determined from a scour evaluation study.

Whenever a rating factor of 4 or below is selected for this item, the rating factor for Item 60 - Substructure, should also be revised to reflect the severity of actual scour conditions and resultant damage to the bridge.

1. Low-risk bridges.

Code	Description
N	Bridge not over waterway.
9	Bridge foundations (including piles) well above flood water elevations.
8	Bridge foundations determined to be stable for assessed or calculated scour conditions; calculated scour is above top of footing (Example A - see figure, p. 7.6).
7	Countermeasures have been installed to correct a previously existing problem with scour. Bridge is no longer scour critical.
5	Bridge foundations determined to be stable for calculated scour conditions; scour within limits of footing or piles (Example B - see figure, p. 7.6).
4	Bridge foundations determined to be stable for calculated scour conditions; field review indicates action is required to protect exposed piles from effects of additional erosion and corrosion.

2. Scour-critical bridges.

Code	Description
3	Bridge is scour-critical; bridge foundations determined to be unstable for calculated scour conditions: - scour within limits of footing or piles (Example B - see figure, p. 7.6) - scour below spread footing base or pile tips (Example C - see figure, p. 7.6)
2	Bridge is scour-critical; field review indicates that extensive scour has occurred at a bridge foundation. Immediate action is required to provide scour countermeasures.
1	Bridge is scour-critical; field review indicates that failure of piers/abutments is imminent. Bridge is closed to traffic.
0	Bridge is scour-critical. Bridge has failed and is closed to traffic.

3. Scour-susceptible bridges.

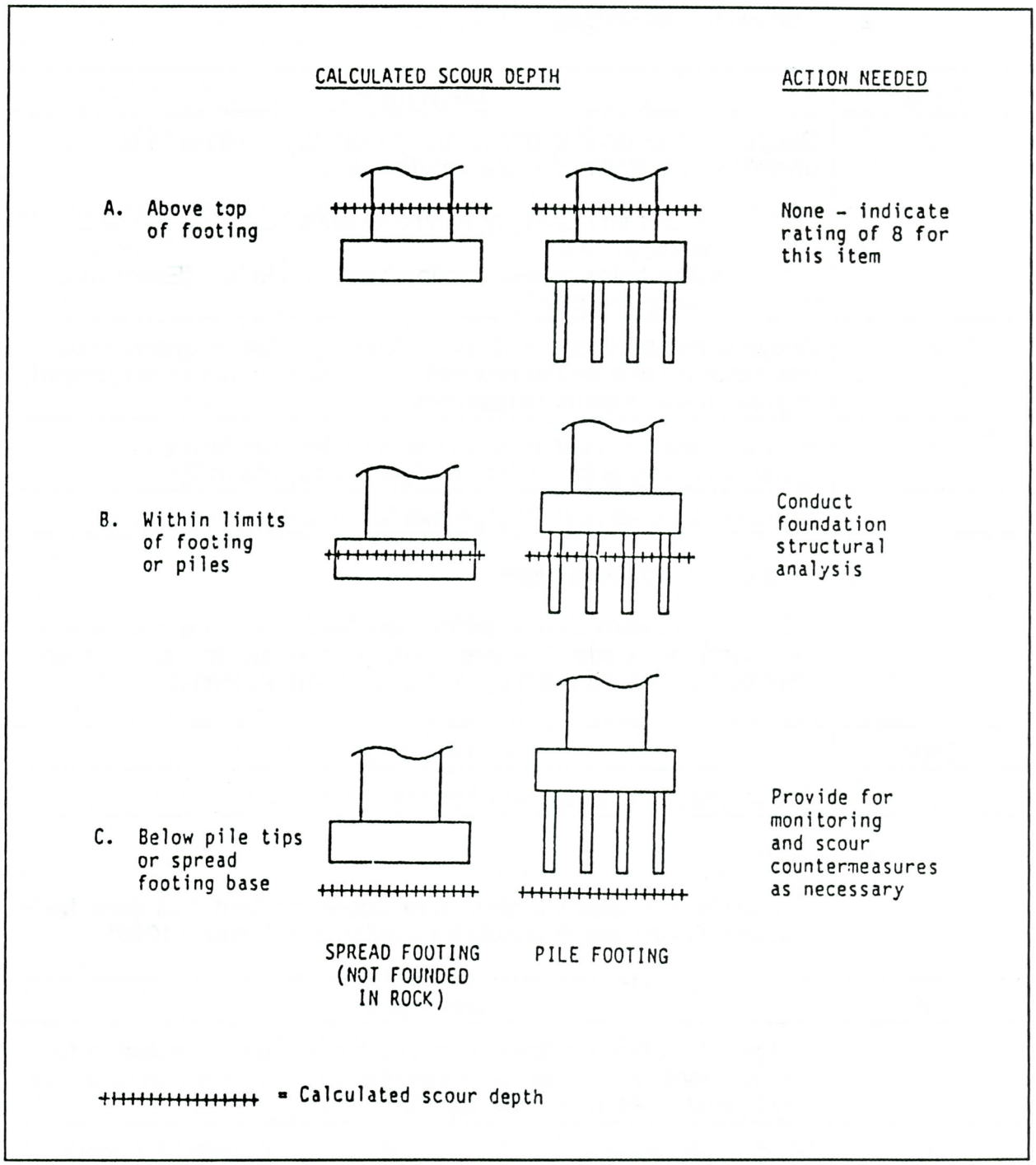
Code 6 assumes that a bridge has been screened and is scour-susceptible. Code 6 is used only to describe the case where a bridge has not yet been evaluated for scour potential.

Code	Description
6	Scour calculation/evaluation has not been made.

4. Other.

Recently, two alpha codes were added to Item 113 (see Metric Coding Guide, which should be available in January 1996).

Code	Description
U	Bridge with "unknown foundation that has not been evaluated for scour. Since risk cannot be determined, flag for monitoring during flood events and, if appropriate, closure.
T	Bridge over "tidal" waters that has not been evaluated for scour, but considered low risk. Bridge will be monitored with regular inspection cycle and with appropriate underwater inspections. ("Unknown" foundations in "tidal" waters should be coded U.)



EXAMPLES FOR CODING GUIDE ITEM 113 - SCOUR-CRITICAL BRIDGES

Technology to identify the type of foundation for bridges with unknown foundations has not yet been fully developed. Since bridges with unknown foundations cannot be evaluated for scour until their foundations have been determined, the stability of bridges with unknown foundations must rely on documentation and comparison of cross sections taken during regular NBIS inspections and after flood events.

Similarly, technology for bridges in tidal zones needs further development. Until this technology is developed, bridges over tidal waterways should be monitored during regular NBIS inspections and after flood events or storm surges.

As general guidance, Interstate bridges with unknown foundations and/or in tidal zones should be evaluated using current technology available and be monitored during and after flood events or storm surges.

H. **Scour-Critical Bridges Require Development of a Plan of Action (see Section IV).**

I. **Bridge Inspectors Should Receive Appropriate Training and Instruction in Inspecting Bridges for Scour.**

1. The bridge inspector should accurately record the present condition of the bridge, including channel cross-section measurements, evidence of pier riprap, and abutment protection.

2. The bridge inspector should identify conditions indicative of potential problems with scour and stream stability.

3. Effective notification procedures should be available to permit the Inspector to promptly communicate findings of actual or potential scour problems.

4. Special attention should be focused on the routine inspection of scour-critical bridges and on the monitoring and closing of scour-critical and other bridges during and after floods.

5. The bridge inspector should be aware of the bed elevation which will cause a bridge to be unstable.

J. **If Monitoring is Used as a Scour Countermeasure**, this needs to be clearly communicated to the Bridge inspectors. Appropriate data collection and inspections must then be completed before, during and after floods.

III. ADDITIONAL CODING AND NOTIFICATION

A. Additional Coding for Scour and Stream Stability.

1. Based on the results of coding Item 113, other items related to scour or bed and bank stability should be reviewed. These include:

   Item 60, Substructure; Item 61, Channel and Channel Protection; Item 71, Waterway Adequacy; Item 92, Critical Feature Inspection (underwater); and Item 93, Critical Feature Inspection Date.

2. Evaluate condition of:

   a. Substructure - Item 60.

      i. This item describes the physical condition of piers, abutments, piles, fenders, footings, or other components. All substructure elements should be inspected for visible signs of distress including evidence of cracking, section loss, settlement, misalignment, **scour**, collision damage, and corrosion. The rating given by **Item 113**, Scour-Critical Bridges, may have a significant effect on **Item 60** if scour has substantially affected the overall condition of the substructure.

      ii. A code of 4 or less in Item 113, Scour-Critical Bridges, may necessitate a revision in this item to reflect the severity of actual scour and resultant damage.

      iii. Coding guidance.

         Code 5 **FAIR CONDITION:** for "minor" scour.

         Code 4 **POOR CONDITION:** for "advanced" scour, removal of bed material below the top of footing or pile cap.

Code 3 **SERIOUS CONDITION:** for scour having partially removed foundation support and seriously affected primary structural components. Local failures possible with resulting fatigue cracks in steel or shear cracks in concrete.

Code 2 **CRITICAL CONDITION:** scour has removed substructure support resulting in advanced deterioration of primary structural elements.

Code 1 **"IMMINENT" FAILURE CONDITION:** scour has removed foundation material resulting in major deterioration in critical structural components with obvious vertical or horizontal movement. Bridge is closed to traffic, but corrective action may put it back in light service.

Code 0 **FAILED CONDITION:** out of service and beyond corrective action.

b. Channel and Channel Protection - Item 61.

i. Evaluates physical characteristics such as stream stability, condition of channel riprap, slope protection and stream control structures, including guide banks.

ii. Undermining of bank and embankment protection.

iii. Coding definition is specific.

c. Waterway Adequacy - Item 71.

i. Evaluates the bridge waterway opening with respect to the passage of flow.

ii. A functional classification shall be used.

iii. Coding definition is specific.

d. Critical Feature Inspection - Items 92 and 93.

i. Critical features which need special emphasis during inspections are identified, along with the designated inspection interval.

ii. Could include the need for an underwater inspection when scour conditions cannot be determined by other means.

iii. Note that Item 91 provides for special nonscheduled inspections after unusual physical traumas, including floods. After and during severe floods, the stability of the substructure of bridges may have to be determined by probing, underwater sensors or other appropriate measures. Underwater inspection by divers may be required for some scour-critical bridges immediately after floods.

3. Enter codes in the respective Items.

4. Evaluate codes assigned in view of Item 113 coding.

5. Ensure that all entries on the list of concerns identified during the Office Review have been addressed.

6. Coding for Items 60, 61 and 71 may indicate imminent need for highway closure. Notify proper authorities immediately.

B. Notification Procedures for Bridge Inspectors.

1. A notification plan should be set up by each bridge owner.

2. Emergency action due to hazardous scour conditions identified during a bridge inspection may be required.

a. Immediately advise police authority concerning potential bridge closure either through designated State highway agency contact or directly, depending on State's notification plan.

b. Through notification of the State highway agency Unit responsible for the scour evaluation program and the Maintenance Unit, activation of the Interdisciplinary Team should be considered to assist in remedial measures.

3. Scour and stream stability issues identified in bridge inspections may require timely but no immediate action and may also necessitate consideration by the Interdisciplinary Team.

4. Complete appropriate bridge inspection paper work in a timely fashion.

5. Routine inspection findings should be routed to Maintenance, Hydraulics, and other Units of the State highway agency as-needed.

NOTES:

IV. PLAN OF ACTION

A. Bridges Identified as Scour Critical, Either by Office or Field Review, Require Development of a Plan of Action.

B. The Plan of Action for Scour-Critical Bridges includes:

1. Timely installation of temporary scour countermeasures, such as monitoring, or riprap and monitoring.

2. Development of a monitoring program which includes both scour measurements and detailed bridge closure instructions. Scour measurements may occur as part of:

   - Two-year inspection cycle with soundings for all bridges.
   - Underwater inspection at 5-year intervals for all bridges.
   - Periodic inspections after major floods or coastal storm surge.
   - Continuous scour measurement with a fixed instrument on the bridge.

3. A schedule for the timely design and construction of permanent scour countermeasures or immediate bridge replacement depending on risk involved.

4. A well-designed monitoring program is an acceptable (permanent) countermeasure; however, the use of monitoring does not fix the scour problem and the bridge would still be considered scour-critical.

5. Special instructions to the bridge inspectors and maintenance personnel, including guidance as to when the bridge should be closed to traffic.

6. Recommended items for consideration when developing a plan of action monitoring plan are outlined in HEC-18, Chapter 7.

7. Appendix F HEC-18 "Scour Measuring and Monitoring Equipment" summarizes the capabilities of currently available scour instrumentation (attached following Lesson 9).

LESSON 8

SCOUR INSPECTION WORKSHOP

OVERVIEW: Method of Instruction: Workshop

Lesson Length: 90 minutes

Resources:

Lesson Outline
Slides
Inspection Forms
Workshop Solution

OBJECTIVES: At the conclusion of this lesson, the Participant shall be able to:

1. **Complete** a scour and stream stability inspection.
2. **Code** a bridge for stream stability and scour.
3. **Determine** follow-up action needed.

LESSON 8

SCOUR INSPECTION WORKSHOP

I. OVERVIEW OF THE PROBLEM

A. **The Inspection Team** is conducting inspections on bridges in northern Pinellas County near Tarpon Springs, Florida (northwest of Tampa).

B. **Bridge Number 150032** which carries U.S. 19 (SR55) over the Anclote River is scheduled for a biennial inspection. Our objective in the next hour is to complete the scour and stream stability portion of the inspection and code Item 113.

C. In the office we have reviewed the last four inspection reports and a **T 5140.23 scour evaluation** which was completed in 1993. Bridge plan and profile have been sketched on the scour inspection cross section sheet and the last five cross sections have been added.

D. **The Bridge was Rated Scour-Susceptible after a Phase I Qualitative Scour Evaluation** in 1993 and a more detailed scour analysis was recommended. This more detailed analysis is scheduled but has not been completed. In the interim, the 1993 evaluation recommended that the bridge should be inspected following flood events or coastal storms resulting in storm surge.

E. **Summary of Findings** from previous inspection reports and 1993 scour evaluations.

1. The bridge was constructed in 1970 over a tidally influenced reach of the Anclote River with tidal marsh upstream and downstream. Several residential developments are being constructed in the surrounding area at the edge of the floodplain. The upstream and downstream channels are vegetated and have stable banks. The right abutment is at the edge of the channel and the left abutment projects about 12 m into the channel.

2. Review of the bridge inspection reports identified deterioration of concrete encasement pier protection. In addition, an area of eroded riprap on the north abutment was reported in 1993.

3. There is a potential for high stage flows from both river flooding and coastal storms or storm surge. Either could cause additional scour of the easily erodible bed material. The Federal Emergency Management Agency (FEMA) 100-year flood elevation for the Anclote River is 10 feet (3.05 m).

4. The foundation of the bridge includes eleven bents with driven steel (12BP74) and concrete piling. Concrete pile jackets, 0.6 m diameter, were placed around each exposed steel pile. Plans indicate the jackets extend from elevation +1.4 m (MSL) to 3 m below existing ground, or to the top of rock.

5. Soil boring logs taken from the Design Plans indicate that the surface bed material is silt and sand. A layer of hard limestone is reported at approximately 16 m below the datum (bridge rail) on most borings.

6. The following data were located during the office review.

   - Design plans dated September 1969, and soil boring logs
   - Pile driving records
   - Bridge inspection reports dated between May 7, 1970, and March 16, 1993
   - Phase I (qualitative) scour evaluation conducted on August 24, 1993

7. The average daily traffic (ADT) for this bridge is 19,467.

Note: Data for this workshop problem have been altered for instructional purposes and do not reflect current conditions at this bridge

II. DETAILED INFORMATION

A. Review of the 1993 Inspection Report Indicates the Following NBIS Coding:

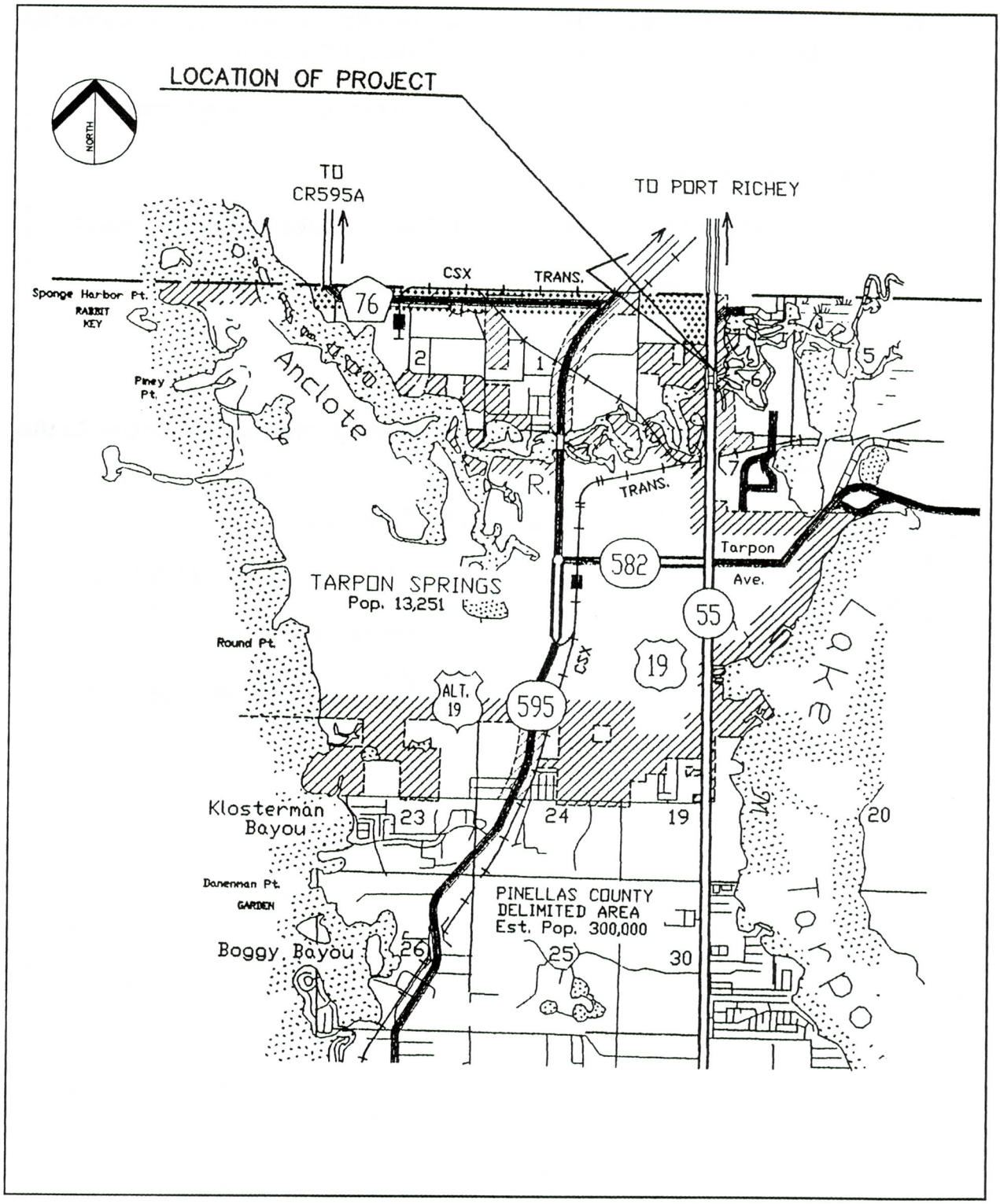
Item 113 Scour	6
Item 60 Substructure	7
Item 61 Channel: Channel Protection	8
Item 71 Waterway Adequacy	8

B. Review of the 1993 T 5140.23 Qualitative Scour Evaluation Reveals the Following Reasons for the Scour-Susceptible Rating:

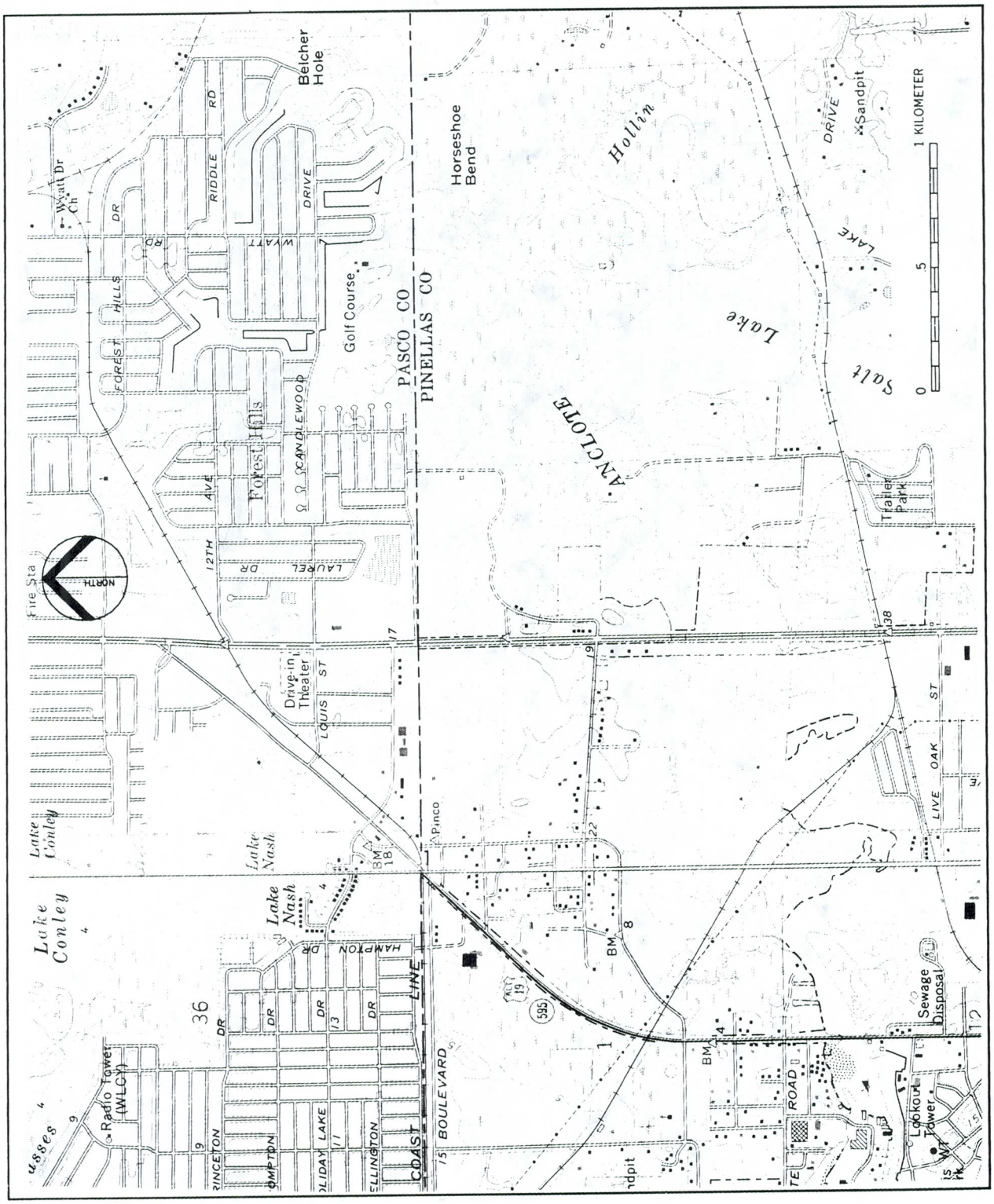
- Bridge susceptible to storm surge and riverine flood flows
- Easily eroded bed material
- Bridge encroaches on channel with significant overbank flow
- Countermeasures at north abutment in poor condition
- Large angle of attack

C. Review of the Files Provided the Following Information for Use in the Inspection:

- A bridge location map from DOT data base
- USGS quad sheets for Elfers and Tarpon Springs (1:24000)
- An aerial photograph of the bridge reach
- A standard set of photographs from the 1993 inspection

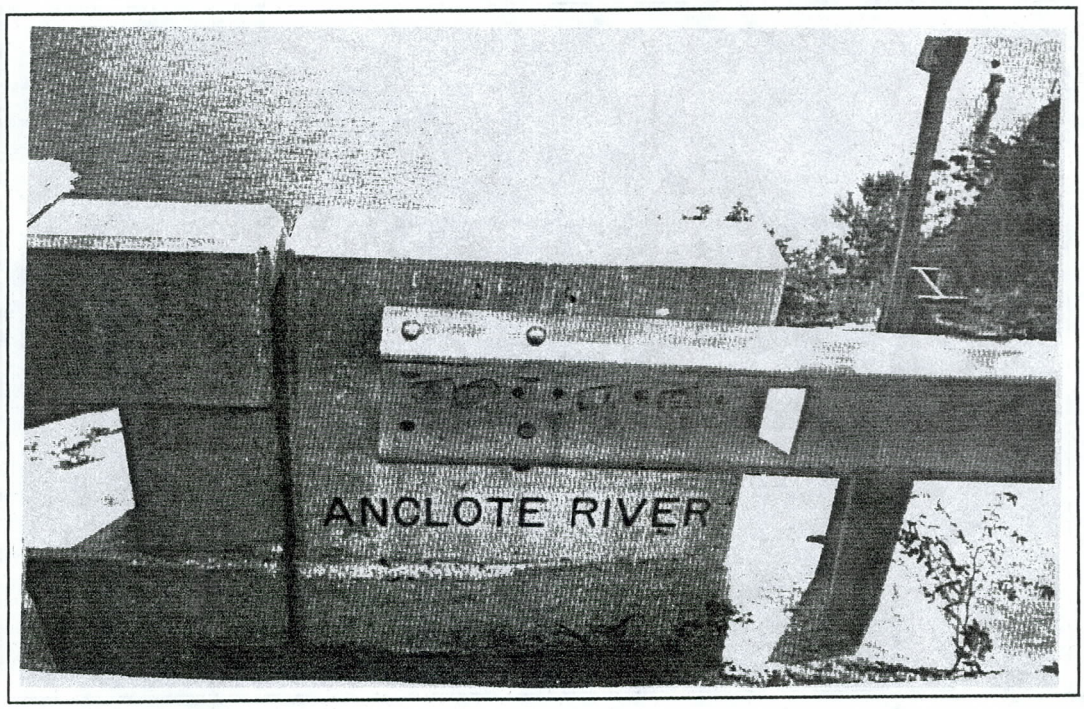


BRIDGE LOCATION MAP

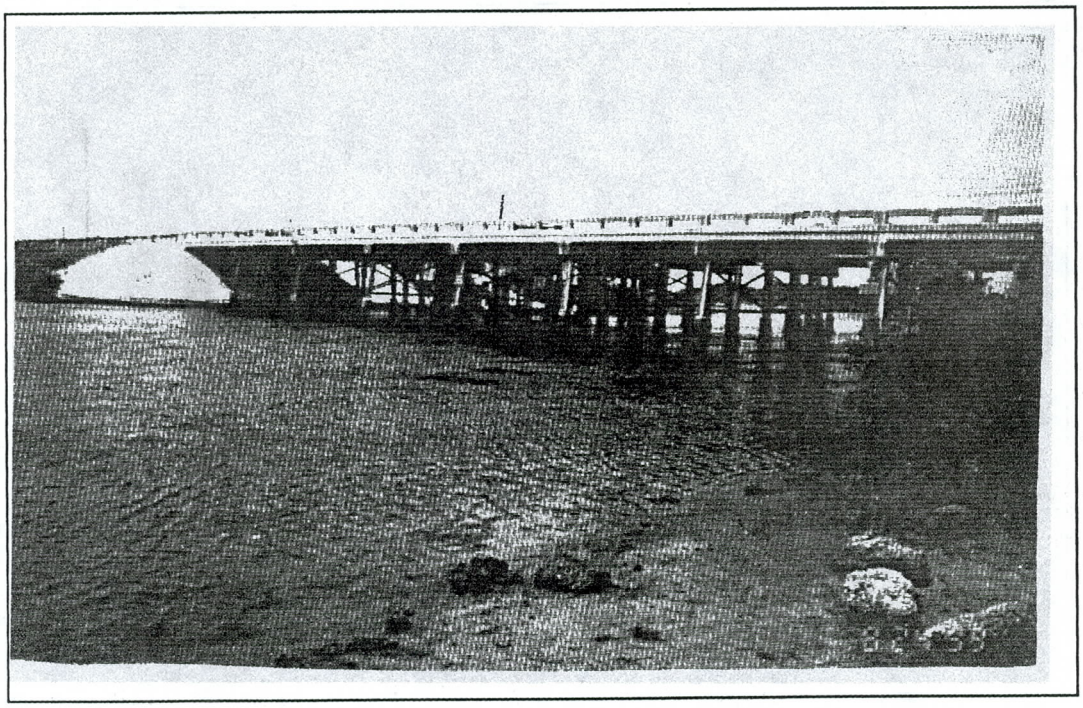


SECTION OF USGS QUAD SHEETS FOR ELFERS AND TARPON SPRINGS, FLORIDA (1:24000)

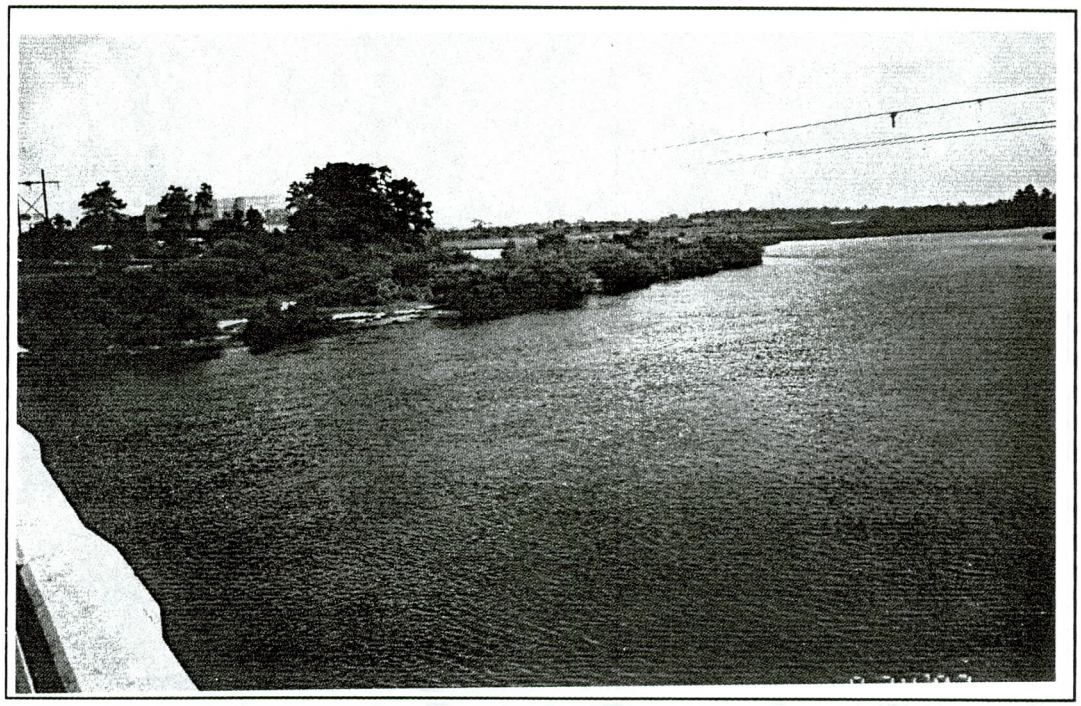
AERIAL PHOTOGRAPH OF THE BRIDGE REACH



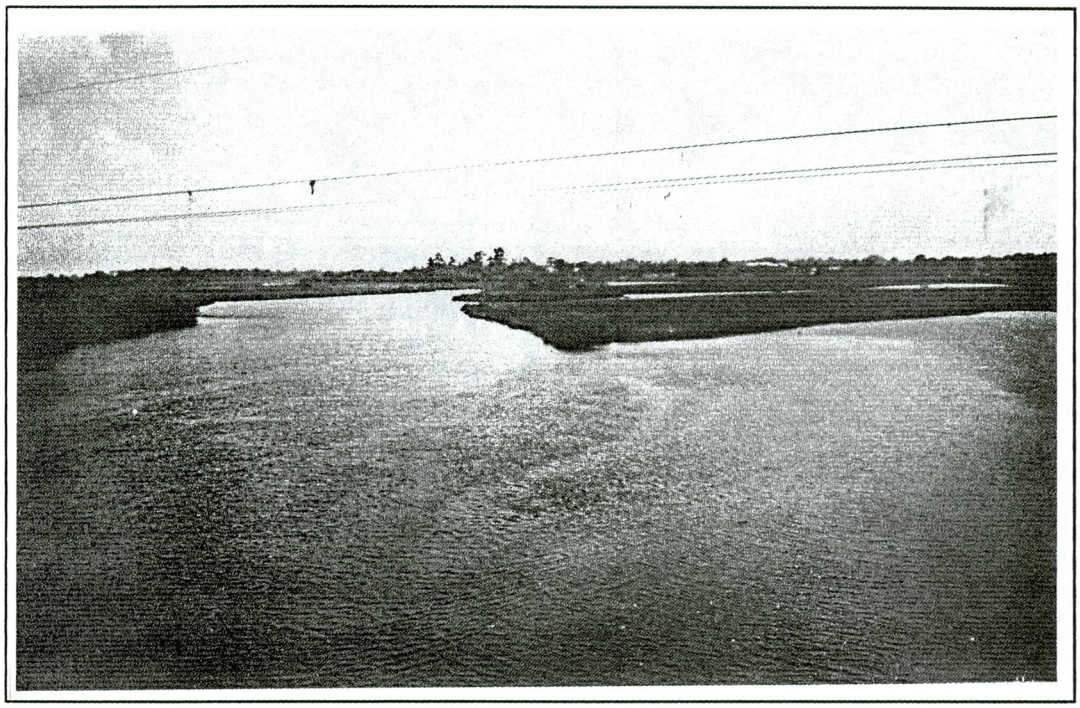
ANCLOTE RIVER



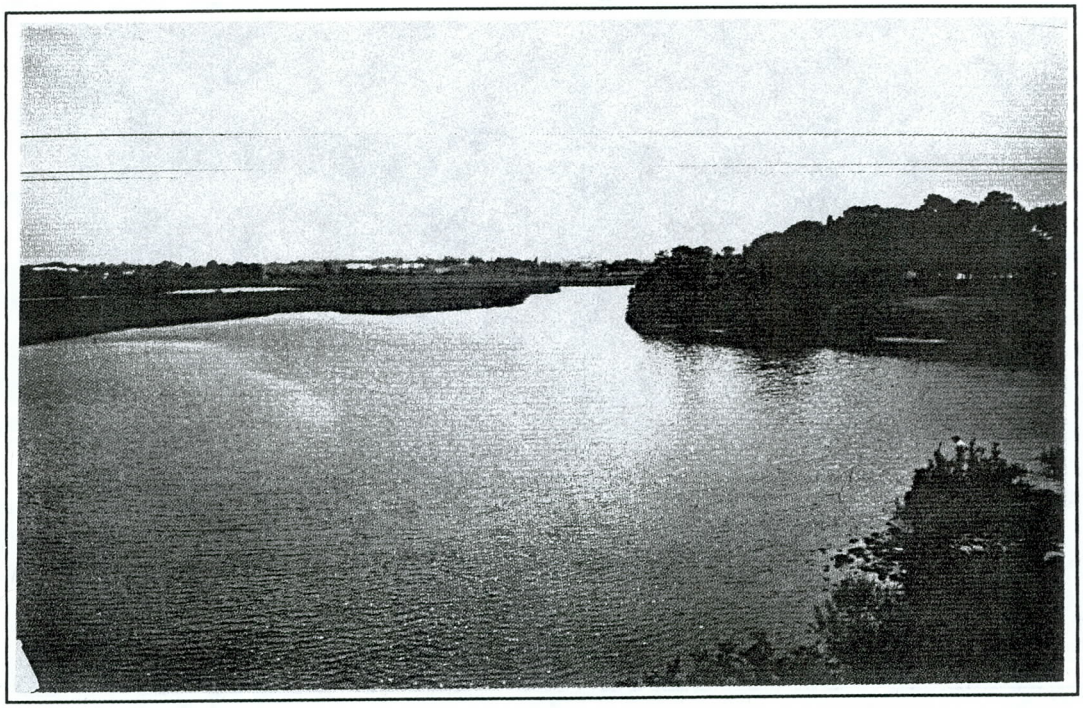
UPSTREAM FACE



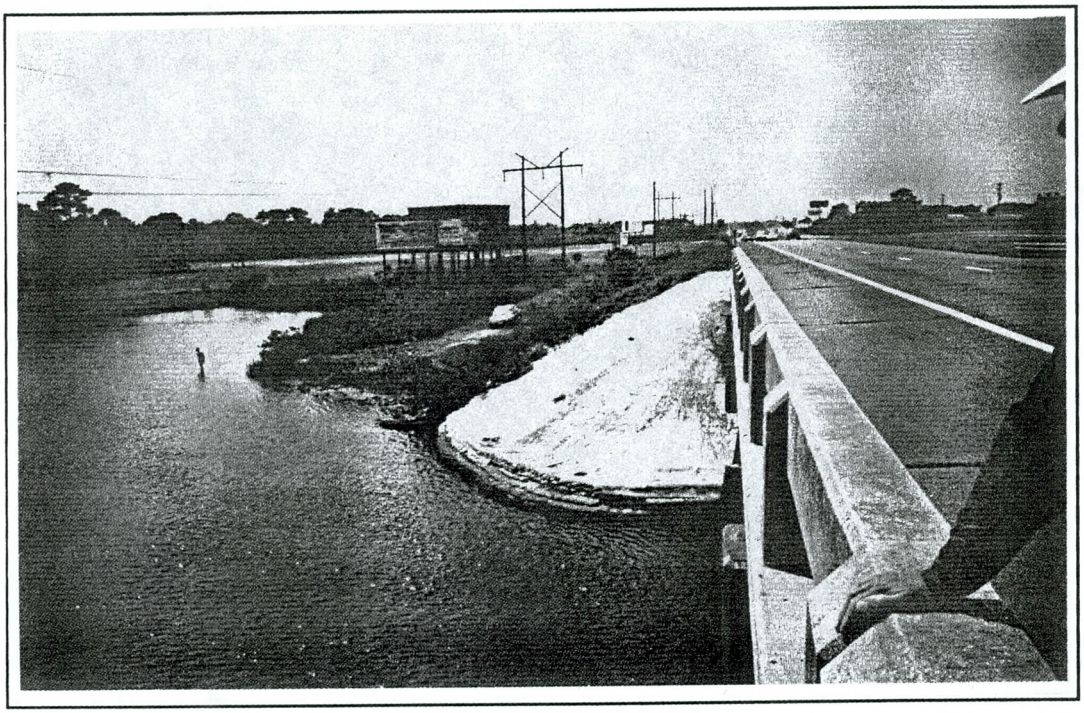
VIEW TO NORTHEAST OF UPSTREAM CHANNEL



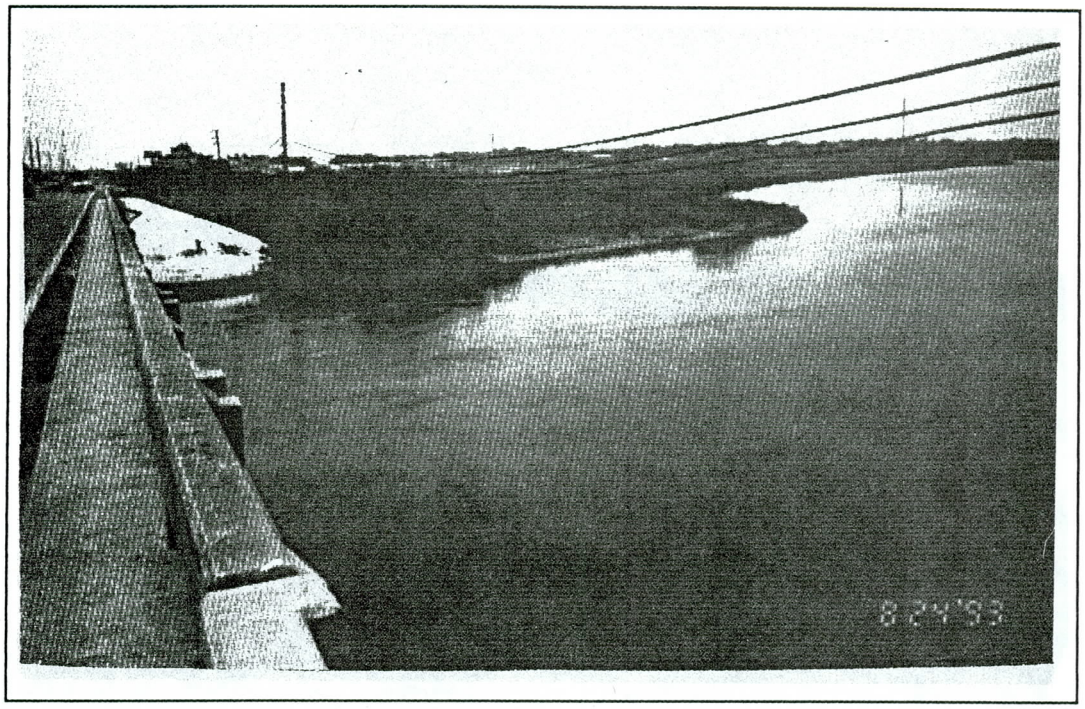
VIEW TO EAST OF UPSTREAM CHANNEL



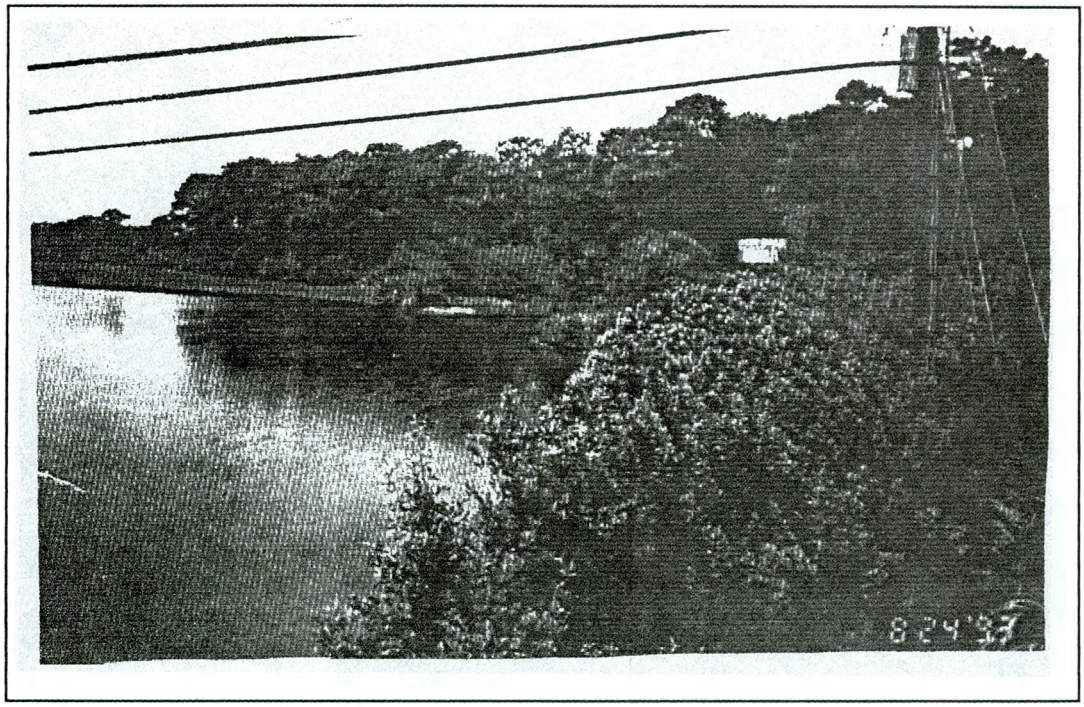
VIEW TO SOUTHEAST OF UPSTREAM CHANNEL



SOUTH ABUTMENT - GROUTED RIPRAP ARMORING



VIEW TO SOUTHWEST OF DOWNSTREAM CHANNEL



VIEW TO WEST OF DOWNSTREAM CHANNEL

III. WORKSHOP PROBLEM

A. During the Field Visit a Portable Sonic Sounding Device was used to Obtain the Following Sounding Information.

	Top of Rail to Water Surface (m)	Sounder Reading		Distance to Streambed (m)
		(ft)	(m)	
Bent 2	4.8	7.9	2.41	7.21
Bent 3	4.8	17.4	5.30	10.10
Bent 4	4.8	22.9	6.98	11.78
Bent 5	4.8	20.7	6.31	11.11
Bent 6	4.8	19.7	6.00	10.80
Bent 7	4.8	17.7	5.39	10.19
Bent 8	4.8	10.8	3.29	8.09
Bent 9	4.8	7.9	2.41	7.21
Bent 10	4.8	8.2	2.50	7.30

Plot these soundings on the Scour Inspection Cross Section Sheet (see Page 8.14).

What problems do the soundings indicate?

What is the most likely cause of this change?

While completing the soundings, you observe a high water mark stain on the piling (normal tide) about 0.5 m above the water surface. The water surface appears low in relation to bank height and the tide is going out.

You estimate the distance from the upstream face of the bridge to the downstream face to be 10.7 m. You drop an orange (biodegradable) at the upstream face and measure its travel time to the downstream face at 15.3 seconds.

What is the surface velocity?

V = _____ = m/s

While inspecting the right (north) abutment you note that the sand cement (grouted bag) slope protection reported as eroding in 1993 has not been repaired and appears to be deteriorating.

B. Using the Information Presented Above, Complete the Scour Inspection Office/Field Review Report.

Note: You can request review of slides, as needed.

SCOUR INSPECTION - SUMMARY SHEET

Bridge No.: 150032	County: Pinellas	Route: SR55(US19)	Waterway: Anclote R.

1. PREVIOUS SCOUR VULNERABILITY RATING			2. CURRENT SCOUR VULNERABILITY RATING		
a. Scour Critical	☐ YES	■ NO	a. Scour Critical	☐ YES	☐ NO
Scour Susceptible	■ YES	☐ NO	Scour Susceptible	☐ YES	☐ NO
Low Risk	☐ YES	■ NO	Low Risk	☐ YES	☐ NO
Tidal	■ YES	☐ NO	Tidal	☐ YES	☐ NO
Foundation	■ Known	☐ Unknown	Foundation	☐ Known	☐ Unknown

b. Reasons for vulnerability rating:

- Bridge susceptible to storm surge and riverine flood flows
- Easily eroded bed material
- Bridge encroaches on channel with significant overbank flow
- Countermeasures at north abutment in poor condition
- Large angle of attack

b. Reasons for vulnerability rating or changes:

3. CODING

	Previous	Recommended*
Item 113 Scour	6	
Item 60 Substructure	7	
Item 61 Channel & Channel Protection	8	
Item 71 Waterway Adequacy	8	

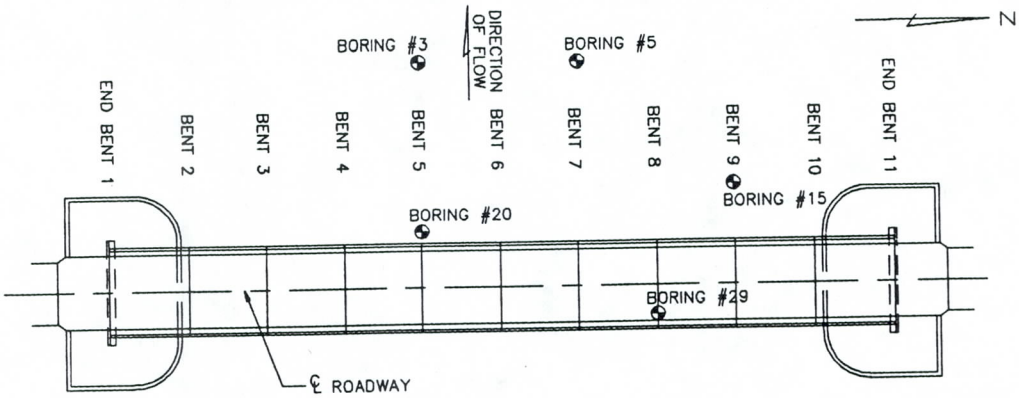
*Major change in condition rating requires corrective action (see 4)

4. RECOMMENDATIONS/ACTION

- ☐ No further action required
- ☐ Qualified interdisciplinary team conduct foundation scour and structural analysis
- ☐ Underwater or follow up inspection required
- ☐ Notification
- ☐ Plan of Action
- ☐ Monitor (specify frequency/criteria
- ☐ Install scour countermeasures
- ☐ Repair existing countermeasures
- ☐ Close Bridge or Contingency Plan

Bridge Number _____

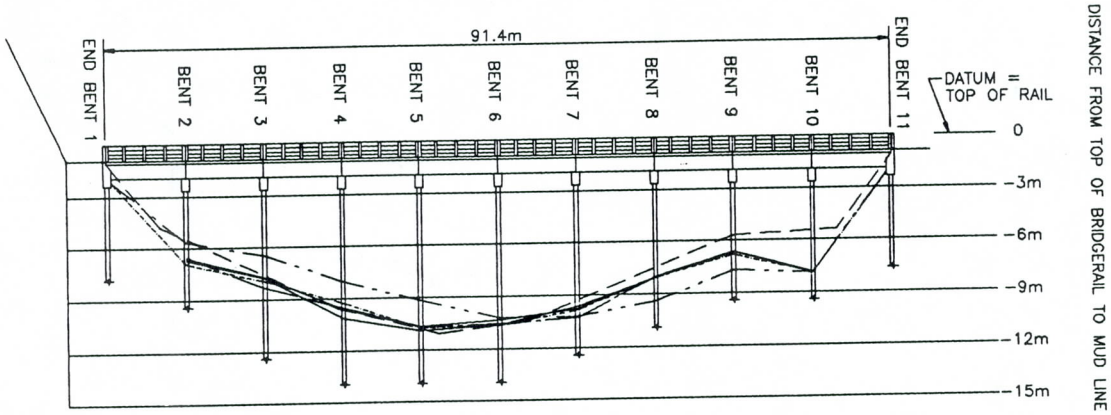
SCOUR INSPECTION CROSS SECTION SHEET



PLAN

STRATA DATA

1 – SILT & SAND
2 – FINE SAND & CLAY
3 – SOFT LIMESTONE
4 – HARD LIMESTONE
5 – SOFT LIMEROCK & CLAY
6 – HARD LIMEROCK
7 – SOFT CLAY
8 – SOFT WATERY CLAY
9 – VOID
10 – HARD CLAY
11 – SOFT ROCK
12 – HARD ROCK



PROFILE

NOTES:

1. DRAWING BASED ON 1969 DESIGN PLANS. (STATE PROJECT NO. 15150-3517)
2. SOIL BORING DATA BASED ON 1969 DESIGN PLANS. (STATE PROJECT NO. 15150-3517)
3. CHANNEL CROSS-SECTION TAKEN FROM LEFT SIDE OF BRIDGE.
4. 1969 MUD LINE WAS SCALED FROM THE DESIGN PLANS AND IS APPROXIMATE.

CHANNEL SOUNDING LEGEND

1993 INSPECTION REPORT
1991 INSPECTION REPORT
1989 INSPECTION REPORT
1987 INSPECTION REPORT
1986 INSPECTION REPORT
1969 DESIGN PLANS

Instructions:

(1) Office Review: Sketch plan and profile of bridge and plot previous cross sections from bridge inspection files or T 5140.23 scour evaluation.

(2) Field Review: Plot cross section (soundings) taken in field and compare with previous cross sections for indications of long-term aggradation, degradation, or local cross section changes.

Bridge Number _____

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

1. SITE FIELD REVIEW

a. Evidence of Scour at Structure (Response: YES/NO or Comment)

1) Abutment Tilting / Moving In: ☐ YES ☐ NO

2) Pier Rotating/Tilting ☐ YES ☐ NO

3) Slopes Washing In / Sloughing: ☐ YES ☐ NO

4) Scour Near Abutments / Bents: ☐ YES ☐ NO

5) Loss of abutment protection or pier riprap ☐ YES ☐ NO

6) Bridge Rail or Deck Sagging: ☐ YES ☐ NO

7) Debris: ☐ YES ☐ NO

b. Feasibility of Monitoring During High Flow

1) Rod / Pole / Weight from Deck: ☐ YES ☐ NO

2) Portable Monitoring Device: ☐ YES ☐ NO

3) Fixed Monitoring Device: ☐ YES ☐ NO

c. Feasibility of Adding Riprap/Other Countermeasures: ☐ YES ☐ NO

2. ABUTMENTS

a. Structure Type: ☐ Bridge ☐ Conc. Box Culvert

b. Abutment Type: ☐ Spill Through ☐ Vertical Wall ☐ Wing Walls ☐ Seawall

c. Foundation	Dimensions (L,W,D) (m)	Embedment (m)	Exposure (m)
☐ Spread Footings			
☐ Pile Caps			
■ Piles	1.5 x 1.5 x 20 (ft)		
☐ Drilled Shaft			

Source of Data: ☐ Field Review ■ Design Plans ☐ As-Builts ☐ Pile Driving Records ☐ Inspection Records ☐ Other

d. Location from Bank	Left (m)	Right (m)	
Set Back			
At Edge of Channel			
Project Into Channel			

e. Protection

1) Countermeasures: ☐ Sand Cement ☐ Riprap ☐ Commercial Block ☐ Grouted ☐ Seawall ☐ Guide Bank ☐ None ☐ Other

2) Condition of Countermeasures: ☐ N/A

	Good	Fair	Poor	Unknown
Left	☐	☐	☐	☐
Right	☐	☐	☐	☐

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

3. PIER

a. Type (Typical or Worst Pier)

☐ Concrete Wall ☐ Pile Bent ☐ Column

b. Location: ☐ Channel ☐ Overbank

c. Shape: ☐ Square ☐ Rounded ☐ Sharp Nose

d. Width ( ) m Length (10.7) m

e. Flow Angle of Attack: Flood Flow (°) Normal Flow (°)

f.

Foundation (Worst Pier)	Dimensions (L,W,D) (m)	Embedment (m)	Exposure (m)
☐ Spread Footing			
☐ Pile Cap			
☐ Piles			
☐ Drilled Shaft			

Source of Data: ☐ Field Review ☐ Design Plans ☐ As-Builts ☐ Pile Driving Records ☐ Inspection Records ☐ Other

g. Protection:

1) Countermeasures: ☐ Sand Cement ☐ Riprap ☐ Commercial Block ☐ Grouted ☐ Seawall ☐ None ☐ Other:

2) Condition of Countermeasures: ☐ N/A ☐ Good ☐ Fair ☐ Poor ☐ Unknown

4. CHANNEL LATERAL STABILITY

a. Bends

1) Bridge Location: ☐ Upstream of Bend ☐ Downstream of Bend ☐ In Bend

2) Channel Migration ☐ Yes ☐ No

3) Countermeasures ☐ Yes ☐ No Type:

b. Bank Condition:

	Upstream	Downstream
1) Eroding	☐	☐
2) Stable	☐	☐
3) Vegetated	☐	☐
4) Seawall	☐	☐

5) Countermeasures ☐ Yes ☐ No Type:

c. Point Bar Under Bridge: ☐ Yes ☐ No

d. Islands or Bars

1) Upstream ☐ Yes ☐ No

2) Downstream ☐ Yes ☐ No

Bridge Number _____

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

5. CHANNEL VERTICAL STABILITY

a. Exposed Footing ☐ Yes ☐ No ☐ Unknown

b. Exposed Piles ☐ Yes ☐ No ☐ Unknown

c. Contraction Scour (Encroachment)

1) Overbank Flow ☐ Left ☐ Yes ☐ No (m)
☐ Right ☐ Yes ☐ No (m)

2) Relief Bridge(s) ☐ Yes ☐ No

3) Roadway Overtopping ☐ Yes ☐ No ☐ Unknown ☐ Possible

4) Bridge Overtopping ☐ Yes ☐ No ☐ Unknown ☐ Possible

d. Long Term

1) Aggradation ☐ Yes ☐ No ☐ Unknown

2) Degradation ☐ Yes ☐ No ☐ Unknown

e. Bed Material

☐ Sand

☐ Gravel

☐ Cobbles

☐ Other

6. OVERALL STREAM STABILITY (complete attached figure)

a. Alluvial Fan ☐ Yes ☐ No

b. Dam or Reservoir ☐ Yes ☐ No ☐ Upstream ☐ Downstream

c. River Form: ☐ Straight ☐ Meandering ☐ Braided ☐ Man Made

d. Instream Mining / Dredging ☐ Yes ☐ No

e. Headcuts (abrupt drop in channel slope) ☐ Yes ☐ No

f. Diversions ☐ Yes ☐ No

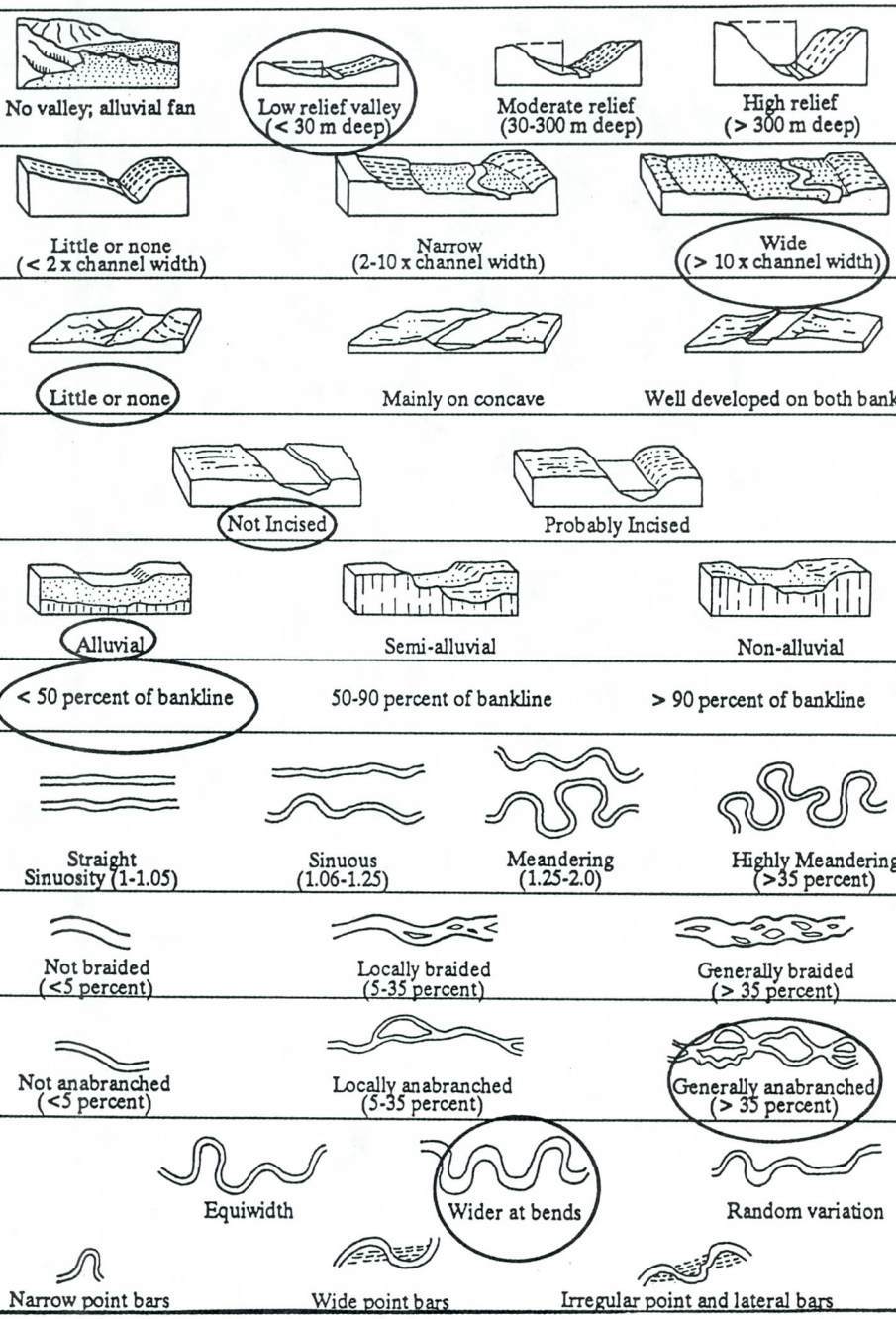
g. Channel Straightening ☐ Yes ☐ No

h. Stream Size: ☐ Small (<30 m) ☐ Medium (30-150 m) ☐ Large (>150 m)

i. Flow Characteristics: ☐ Ephemeral ☐ Intermittent ☐ Perennial ☐ Tidal

Bridge Number _____

STREAM SIZE	Small (<30 m wide)		Medium (30-150 m)	Wide (> 150 m)
FLOW HABIT	Ephemeral	(Intermittant)	Perennial but flashy	Perennial
BED MATERIAL	Silt-Clay	Silt	Sand	Gravel	Cobble or Boulder
VALLEY SETTING	No valley; alluvial fan	Low relief valley (< 30 m deep)	Moderate relief (30-300 m deep)	High relief (> 300 m deep)
FLOODPLAINS	Little or none (< 2 x channel width)	Narrow (2-10 x channel width)	Wide (> 10 x channel width)
NATURAL LEVEES	Little or none	Mainly on concave	Well developed on both banks
APPARENT INCISION	Not Incised	Probably Incised
CHANNEL BOUNDARIES	Alluvial	Semi-alluvial	Non-alluvial
TREE COVER ON BANKS	< 50 percent of bankline	50-90 percent of bankline	> 90 percent of bankline
SINUOSITY	Straight Sinuosity (1-1.05)	Sinuous (1.06-1.25)	Meandering (1.25-2.0)	Highly Meandering (>35 percent)
BRAIDED STREAMS	Not braided (<5 percent)	Locally braided (5-35 percent)	Generally braided (> 35 percent)
ANABRANCHED STREAMS	Not anabranched (<5 percent)	Locally anabranched (5-35 percent)	Generally anabranched (> 35 percent)
VARIABILITY OF WIDTH AND DEVELOPMENT OF BARS	Equiwidth	Wider at bends	Random variation
	Narrow point bars	Wide point bars	Irregular point and lateral bars



FACTORS THAT AFFECT STREAM STABILITY

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

7. OTHER CONSIDERATIONS

a. Sediment Transport:

1) ☐ Live-Bed Condition ☐ Clear-Water Condition ☐ Unknown

2) Armored Bed ☐ Yes ☐ No ☐ Unknown

b. Watershed: ☐ Agricultural ☐ Forested ☐ Swamp ☐ Urban

c. Tributaries ☐ Upstream ☐ Downstream ☐ No Factor

d. Distance to confluence of next stream or water body - km (2.5) upstream

e. In-channel vegetation ☐ None ☐ Light ☐ Heavy

f. Overbank vegetation ☐ None ☐ Light ☐ Heavy

8. TIDAL WATERWAYS

a. Tidal Influence: ☐ Yes ☐ No ☐ Unknown ☐ Possible

b. Tidal Features: ☐ Bay ☐ Estuary ☐ Inlet ☐ Barrier Island

c. Tidal Conditions:

1) Normal Range ☐ Field Observation ☐ Tide Table

2) Storm Surge ☐ Yes ☐ No

3) Seiching (wind set up) ☐ Yes ☐ No

4) Distance to coast - km (1.6) Km Along Thalweg (1.6)

5) Traffic: ☐ Ship ☐ Recreation ☐ Commercial ☐ Barge
☐ Intracoastal Waterway

9. ADDITIONAL COMMENTS

a. Photographs: ☐ Bridge Number ☐ Upstream Channel ☐ Upstream Face
☐ Downstream Channel ☐ Downstream Face

b. Conditions at time of inspection:

1) Flow conditions (riverine) ☐ Low Flow ☐ Bank Full ☐ Overbank

2) Flow conditions (tidal) ☐ Low Tide ☐ Slack Tide ☐ High Tide
☐ Ebb Tide ☐ Flood Tide

3) Flow velocity: Surface velocity can be estimated in the field from the time of travel of a floating object over a known distance.

$$V = \frac{\text{distance}}{\text{time}} = ____\text{m/s}$$

4) Flow depth ( ) m

5) High water mark ( ) m above normal flow

c. Remarks:

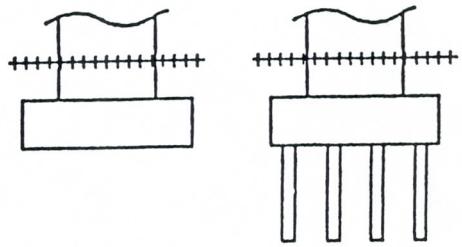
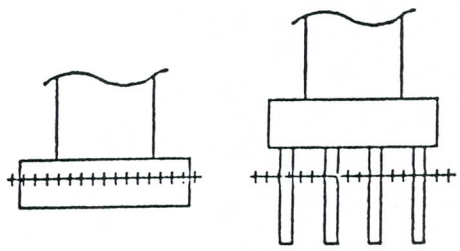
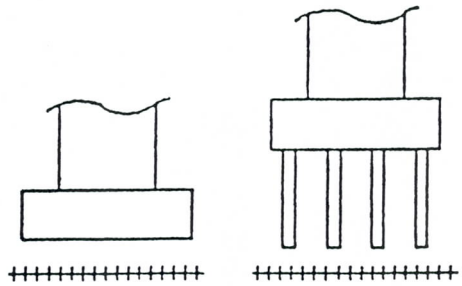
Field Inspectors:

Date of Inspection: Time of Inspection:

SCOUR INSPECTION CODING SHEET FOR ITEM 113

Code	Description
	LOW-RISK BRIDGES
N	Bridge not over waterway.
9	Bridge foundations (including piles) well above flood water elevations.
8	Bridge foundations determined to be stable for assessed or calculated scour conditions; calculated scour is above top of footing (Example A).
7	Countermeasures have been installed to correct a previously existing problem with scour. Bridge is no longer scour critical.
5	Bridge foundations determined to be stable for calculated scour conditions; scour within limits of footing or piles (Example B).
4	Bridge foundations determined to be stable for calculated scour conditions; field review indicates action is required to protect exposed piles from effects of additional erosion and corrosion.
	SCOUR-CRITICAL BRIDGES
3	Bridge is scour critical; bridge foundations determined to be unstable for calculated scour conditions: - scour within limits of footing or piles (Example B) - scour below spread footing base or pile tips (Example C)
2	Bridge is scour critical; field review indicates that extensive scour has occurred at a bridge foundation. Immediate action is required to provide scour countermeasures.
1	Bridges is scour critical; field review indicates that failure of piers/abutments is imminent. Bridge is closed to traffic.
0	Bridge is scour critical. Bridge has failed and is closed to traffic.
	SCOUR SUSCEPTIBLE BRIDGES
6	Scour calculation/evaluation has not been made.
	OTHER
U	Bridge with "unknown" foundation that has not been evaluated for scour. Since risk cannot be determined, flag for monitoring during flood events and, if appropriate, closure.
T	Bridge over "tidal" waters that has not been evaluated for scour, but considered low risk. Bridge will be monitored with regular inspection cycle and with appropriate underwater inspections. ("Unknown" foundations in "tidal" waters should be coded U.)

Bridge Number _____

	CALCULATED SCOUR DEPTH	ACTION NEEDED
A. Above top of footing		None - indicate rating of 8 for this item
B. Within limits of footing or piles		Conduct foundation structural analysis
C. Below pile tips or spread footing base		Provide for monitoring and scour countermeasures as necessary
	SPREAD FOOTING (NOT FOUNDED IN ROCK) / PILE FOOTING	

++++++++++++++++ = Calculated scour depth

EXAMPLES FOR CODING GUIDE ITEM 113-SCOUR CRITICAL BRIDGES

C. **Using the results of the field visit** as noted on the Scour Inspection Office/Field Report and the soundings taken in the field, complete Part 2 of the Scour Inspection Summary Sheet.

D. **Using the Scour Inspection Coding Sheet for Item 113**, determine a current scour coding.

E. **Reevaluate other NBIS coding items related to scour** (Items 60, 61, and 71) and recode as appropriate.

F. **Complete Part 4 of the Scour Inspection Summary Sheet - Recommendations/Action**.

What follow-up action is required?

If a Plan of Action is recommended, what are the essential elements?

Discuss any other observations and potential problems for this bridge as a result of your inspection for scour.

A solution to the workshop problem is attached following Lesson 9.

LESSON 9

SUMMARY OF SCOUR INSPECTION PROCEDURES

OVERVIEW: Method of Instruction: Lecture

Lesson Length: 30 minutes

Resources:

Lesson Outline
Slides

OBJECTIVES: At the conclusion of this lesson, the Participant shall be able to:

1. **Identify** the steps necessary to complete a scour and stream stability inspection.
2. **Understand** a standardized procedure for completing scour and stream stability inspections.
3. **Relate** a scour and stream stability inspection to NBIS coding.

LESSON 9

SUMMARY OF SCOUR INSPECTION PROCEDURES

I. BRIDGE INSPECTION PROCEDURES - STREAM STABILITY AND SCOUR

A. This lesson summarizes the procedures applied to a field problem in the scour inspection workshop (Lesson 8). Detailed guidance is provided on the use of the Scour Inspection Summary Sheet and the Scour Inspection Office/Field Review Report in relation to the National Bridge Inspection Standards.

B. Inspection Objectives.

1. Accurately record present condition of bridge and channel.

2. Identify potential problems from scour and stream instability for further review and evaluation by others.

C. Office Review.

1. Prior to bridge inspection.

2. Consider these issues at each site:

   a. Previous 2-year cycle bridge inspections.

   b. Previous underwater inspections.

   c. Status of scour evaluation (T 5140.23).

      i. Unknown foundation?

      ii. Scour critical bridge?

      iii. Bridge being monitored?

      iv. Scour countermeasures?

      v. Plan of action?

d. Previous cross sections.

   i. Location.

   ii. Plot and compare.

e. Determine equipment needed.

f. Compare sketches and ground and aerial photos.

g. Confer with Maintenance Staff for observed problems.

h. Confer with Hydraulic Unit for unusual discharges and any other hydraulic aspect(s) impacting the site.

i. Develop a list of concerns that will require special attention during the inspection.

NOTES:

II. STANDARDIZED PROCEDURES

A. Inspection Procedures.

1. Standardized procedures for inspecting bridges for stream stability and scour will ensure that results of the bridge inspection can be replicated.

2. A standardized approach will permit comparing sequential inspection results to detect progressive scour and stream instability problems as they develop.

3. Standardized procedures will support development of a district-wide or state-wide database on bridge scour status.

4. Stream stability and scour inspection procedures should incorporate the guidelines of HEC-20, Stream Stability at Highway Structures, and HEC-18, Scour at Bridges.

B. Suggested Approach.

1. A suggested approach to scour and stream stability inspections is presented as an Office/Field Review Report.

2. This standardized approach was developed in cooperation with Florida DOT to support T 5140.23 scour evaluations and has been revised to support the broader requirements of the normal inspection cycle and NBIS coding.

3. Because of the complexity of inspecting stream stability and scour factors, the approach is qualitative, requiring an understanding of the processes involved. Good judgment and experience are required to arrive at the scour vulnerability rating.

4. **A detailed scour evaluation requires analyses by qualified hydraulic, structural, and geotechnical engineers. The qualitative evaluation resulting from this suggested approach provides guidance to the inspector to determine if a major change has occurred in any coding item related to stream stability and scour. If so, the interdisciplinary team of engineers must reevaluate the bridge.**

C. **A Suggested Office/Field Review Report Format** is presented on pages 9.4-9.12. Explanation of the sections of the report is presented in Section D and guidelines for the scour vulnerability rating are presented in Section E.

SCOUR INSPECTION - SUMMARY SHEET

Bridge No.:	County:	Route:	Waterway:

1. PREVIOUS SCOUR VULNERABILITY RATING			2. CURRENT SCOUR VULNERABILITY RATING		
a. Scour Critical	☐ YES	☐ NO	a. Scour Critical	☐ YES	☐ NO
Scour Susceptible	☐ YES	☐ NO	Scour Susceptible	☐ YES	☐ NO
Low Risk	☐ YES	☐ NO	Low Risk	☐ YES	☐ NO
Tidal	☐ YES	☐ NO	Tidal	☐ YES	☐ NO
Foundation	☐ Known	☐ Unknown	Foundation	☐ Known	☐ Unknown
b. Reasons for vulnerability rating:			b. Reasons for vulnerability rating or changes:		

3. CODING

	Previous	Recommended*
Item 113 Scour	_____	_____
Item 60 Substructure	_____	_____
Item 61 Channel & Channel Protection	_____	_____
Item 71 Waterway Adequacy	_____	_____

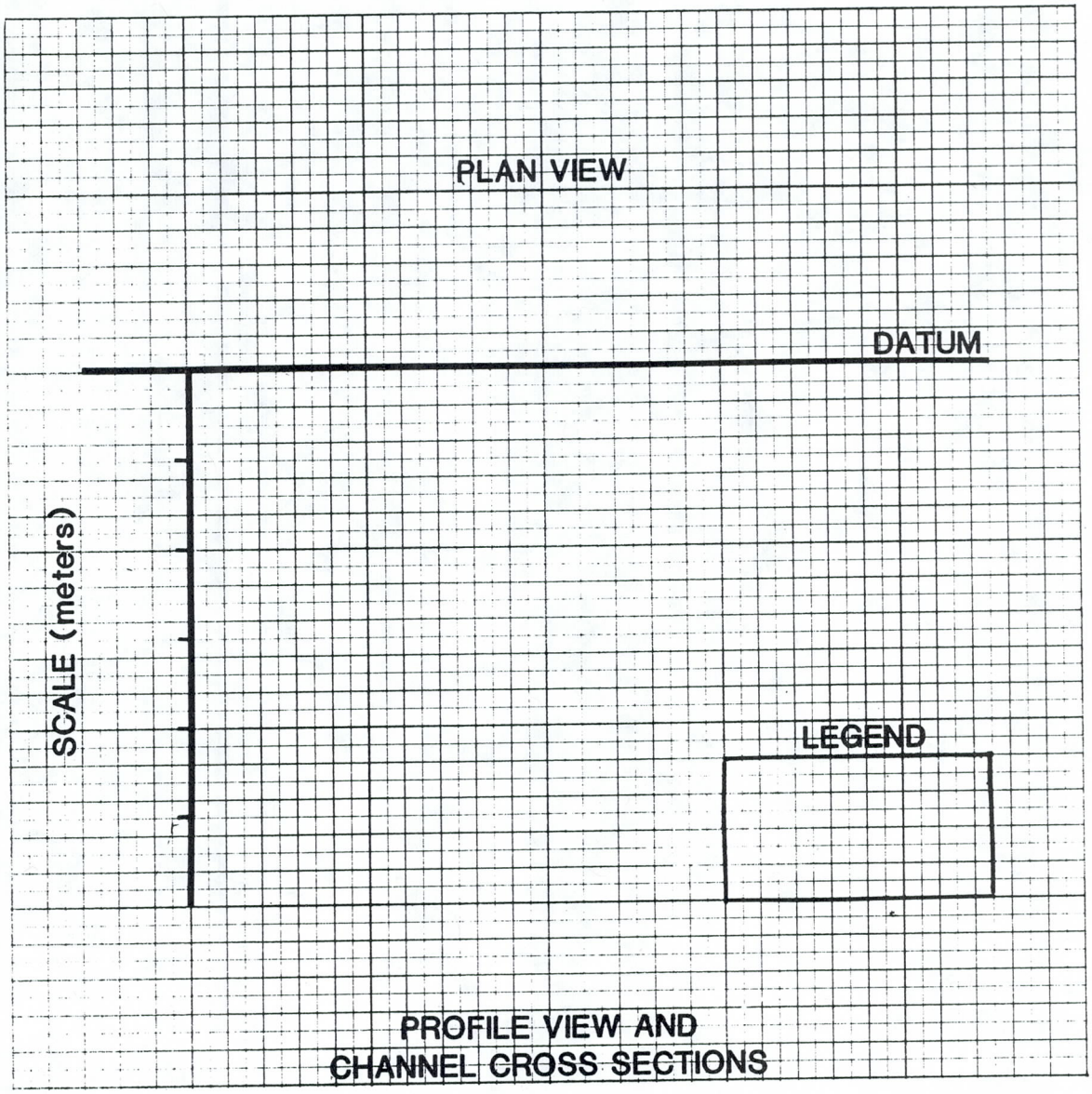
*Major change in condition rating requires corrective action (see 4)

4. RECOMMENDATIONS/ACTION

- ☐ No further action required
- ☐ Qualified interdisciplinary team conduct foundation scour and structural analysis
- ☐ Underwater or follow up inspection required
- ☐ Notification
- ☐ Plan of Action
- ☐ Monitor (specify frequency/criteria
- ☐ Install scour countermeasures
- ☐ Repair existing countermeasures
- ☐ Close Bridge or Contingency Plan

Bridge Number _____

SCOUR INSPECTION CROSS SECTION SHEET



Instructions:

(1) Office Review: Sketch plan and profile of bridge and plot previous cross sections from bridge inspection files or T 5140.23 scour evaluation.

(2) Field Review: Plot cross section (soundings) taken in field and compare with previous cross sections for indications of long-term aggradation, degradation, or local cross section changes.

Bridge Number _____

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

1. SITE FIELD REVIEW

a. Evidence of Scour at Structure (Response: YES/NO or Comment)

1) Abutment Tilting / Moving In: ☐ YES ☐ NO

2) Pier Rotating/Tilting ☐ YES ☐ NO

3) Slopes Washing In / Sloughing: ☐ YES ☐ NO

4) Scour Near Abutments / Bents: ☐ YES ☐ NO

5) Loss of abutment protection or pier riprap ☐ YES ☐ NO

6) Bridge Rail or Deck Sagging: ☐ YES ☐ NO

7) Debris: ☐ YES ☐ NO

b. Feasibility of Monitoring During High Flow

1) Rod / Pole / Weight from Deck: ☐ YES ☐ NO

2) Portable Monitoring Device: ☐ YES ☐ NO

3) Fixed Monitoring Device: ☐ YES ☐ NO

c. Feasibility of Adding Riprap/Other Countermeasures: ☐ YES ☐ NO

2. ABUTMENTS

a. Structure Type: ☐ Bridge ☐ Conc. Box Culvert

b. Abutment Type: ☐ Spill Through ☐ Vertical Wall ☐ Wing Walls ☐ Seawall

c. Foundation	Dimensions (L,W,D) (m)	Embedment (m)	Exposure (m)
☐ Spread Footings			
☐ Pile Caps			
☐ Piles			
☐ Drilled Shaft			

Source of Data: ☐ Field Review ☐ Design Plans ☐ As-Builts ☐ Pile Driving Records ☐ Inspection Records ☐ Other

d. Location from Bank	Left (m)	Right (m)	
Set Back			
At Edge of Channel			
Project Into Channel			

e. Protection

1) Countermeasures: ☐ Sand Cement ☐ Riprap ☐ Commercial Block ☐ Grouted ☐ Seawall ☐ Guide Bank ☐ None ☐ Other

2) Condition of Countermeasures: ☐ N/A

	Good	Fair	Poor	Unknown
Left	☐	☐	☐	☐
Right	☐	☐	☐	☐

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

3. PIER

a. Type (Typical or Worst Pier)

☐ Concrete Wall ☐ Pile Bent ☐ Column

b. Location: ☐ Channel ☐ Overbank

c. Shape: ☐ Square ☐ Rounded ☐ Sharp Nose

d. Width ( ) m Length ( ) m

e. Flow Angle of Attack: Flood Flow (°) Normal Flow (°)

f.

Foundation (Worst Pier)	Dimensions (L,W,D) (m)	Embedment (m)	Exposure (m)
☐ Spread Footing			
☐ Pile Cap			
☐ Piles			
☐ Drilled Shaft			

Source of Data: ☐ Field Review ☐ Design Plans ☐ As-Builts ☐ Pile Driving Records ☐ Inspection Records ☐ Other

g. Protection:

1) Countermeasures: ☐ Sand Cement ☐ Riprap ☐ Commercial Block ☐ Grouted ☐ Seawall ☐ None ☐ Other:

2) Condition of Countermeasures: ☐ N/A ☐ Good ☐ Fair ☐ Poor ☐ Unknown

4. CHANNEL LATERAL STABILITY

a. Bends

1) Bridge Location: ☐ Upstream of Bend ☐ Downstream of Bend ☐ In Bend

2) Channel Migration ☐ Yes ☐ No

3) Countermeasures ☐ Yes ☐ No Type:

b. Bank Condition:

	Upstream	Downstream
1) Eroding	☐	☐
2) Stable	☐	☐
3) Vegetated	☐	☐
4) Seawall	☐	☐

5) Countermeasures ☐ Yes ☐ No Type:

c. Point Bar Under Bridge: ☐ Yes ☐ No

d. Islands or Bars

1) Upstream ☐ Yes ☐ No

2) Downstream ☐ Yes ☐ No

Bridge Number _____

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

5. CHANNEL VERTICAL STABILITY

a. Exposed Footing ☐ Yes ☐ No ☐ Unknown

b. Exposed Piles ☐ Yes ☐ No ☐ Unknown

c. Contraction Scour (Encroachment)

1) Overbank Flow ☐ Left ☐ Yes ☐ No (m)
☐ Right ☐ Yes ☐ No (m)

2) Relief Bridge(s) ☐ Yes ☐ No

3) Roadway Overtopping ☐ Yes ☐ No ☐ Unknown ☐ Possible

4) Bridge Overtopping ☐ Yes ☐ No ☐ Unknown ☐ Possible

d. Long Term

1) Aggradation ☐ Yes ☐ No ☐ Unknown

2) Degradation ☐ Yes ☐ No ☐ Unknown

e. Bed Material

☐ Sand

☐ Gravel

☐ Cobbles

☐ Other

6. OVERALL STREAM STABILITY (complete attached figure)

a. Alluvial Fan ☐ Yes ☐ No

b. Dam or Reservoir ☐ Yes ☐ No ☐ Upstream ☐ Downstream

c. River Form: ☐ Straight ☐ Meandering ☐ Braided ☐ Man Made

d. Instream Mining / Dredging ☐ Yes ☐ No

e. Headcuts (abrupt drop in channel slope) ☐ Yes ☐ No

f. Diversions ☐ Yes ☐ No

g. Channel Straightening ☐ Yes ☐ No

h. Stream Size: ☐ Small (<30 m) ☐ Medium (30-150 m) ☐ Large (>150 m)

i. Flow Characteristics: ☐ Ephemeral ☐ Intermittent ☐ Perennial ☐ Tidal

Bridge Number _____

STREAM SIZE	Small (<30 m wide)		Medium (30-150 m)		Wide (> 150 m)
FLOW HABIT	Ephemeral	(Intermittant)		Perennial but flashy	Perennial
BED MATERIAL	Silt-Clay	Silt	Sand	Gravel	Cobble or Boulder
VALLEY SETTING	No valley; alluvial fan	Low relief valley (< 30 m deep)		Moderate relief (30-300 m deep)	High relief (> 300 m deep)
FLOODPLAINS	Little or none (< 2 x channel width)		Narrow (2-10 x channel width)		Wide (> 10 x channel width)
NATURAL LEVEES	Little or none		Mainly on concave		Well developed on both banks
APPARENT INCISION	Not Incised			Probably Incised	
CHANNEL BOUNDARIES	Alluvial		Semi-alluvial		Non-alluvial
TREE COVER ON BANKS (SECT. 2.2.8)	< 50 percent of bankline		50-90 percent of bankline		> 90 percent of bankline
SINUOSITY	Straight Sinuosity (1-1.05)		Sinuous (1.06-1.25)	Meandering (1.25-2.0)	Highly Meandering (>35 percent)
BRAIDED STREAMS	Not braided (<5 percent)		Locally braided (5-35 percent)		Generally braided (> 35 percent)
ANABRANCHED STREAMS	Not anabranched (<5 percent)		Locally anabranched (5-35 percent)		Generally anabranched (> 35 percent)
VARIABILITY OF WIDTH AND DEVELOPMENT OF BARS	Narrow point bars	Equiwidth	Wide point bars	Wider at bends	Irregular point and lateral bars / Random variation

FACTORS THAT AFFECT STREAM STABILITY

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

7. OTHER CONSIDERATIONS

a. Sediment Transport:

1) ☐ Live-Bed Condition ☐ Clear-Water Condition ☐ Unknown

2) Armored Bed ☐ Yes ☐ No ☐ Unknown

b. Watershed: ☐ Agricultural ☐ Forested ☐ Swamp ☐ Urban

c. Tributaries ☐ Upstream ☐ Downstream ☐ No Factor

d. Distance to confluence of next stream or water body - km ( )

e. In-channel vegetation ☐ None ☐ Light ☐ Heavy

f. Overbank vegetation ☐ None ☐ Light ☐ Heavy

8. TIDAL WATERWAYS

a. Tidal Influence: ☐ Yes ☐ No ☐ Unknown ☐ Possible

b. Tidal Features: ☐ Bay ☐ Estuary ☐ Inlet ☐ Barrier Island

c. Tidal Conditions:

1) Normal Range ☐ Field Observation ☐ Tide Table

2) Storm Surge ☐ Yes ☐ No

3) Seiching (wind set up) ☐ Yes ☐ No

4) Distance to coast - km ( ) Km Along Thalweg ( )

5) Traffic: ☐ Ship ☐ Recreation ☐ Commercial ☐ Barge
☐ Intracoastal Waterway

9. ADDITIONAL COMMENTS

a. Photographs: ☐ Bridge Number ☐ Upstream Channel ☐ Upstream Face
☐ Downstream Channel ☐ Downstream Face

b. Conditions at time of inspection:

1) Flow conditions (riverine) ☐ Low Flow ☐ Bank Full ☐ Overbank

2) Flow conditions (tidal) ☐ Low Tide ☐ Slack Tide ☐ High Tide
☐ Ebb Tide ☐ Flood Tide

3) Flow velocity: Surface velocity can be estimated in the field from the time of travel of a floating object over a known distance.

$$V = \frac{\text{distance}}{\text{time}} = _____ \text{m/s}$$

4) Flow depth ( ) m

5) High water mark ( ) m above normal flow

c. Remarks:

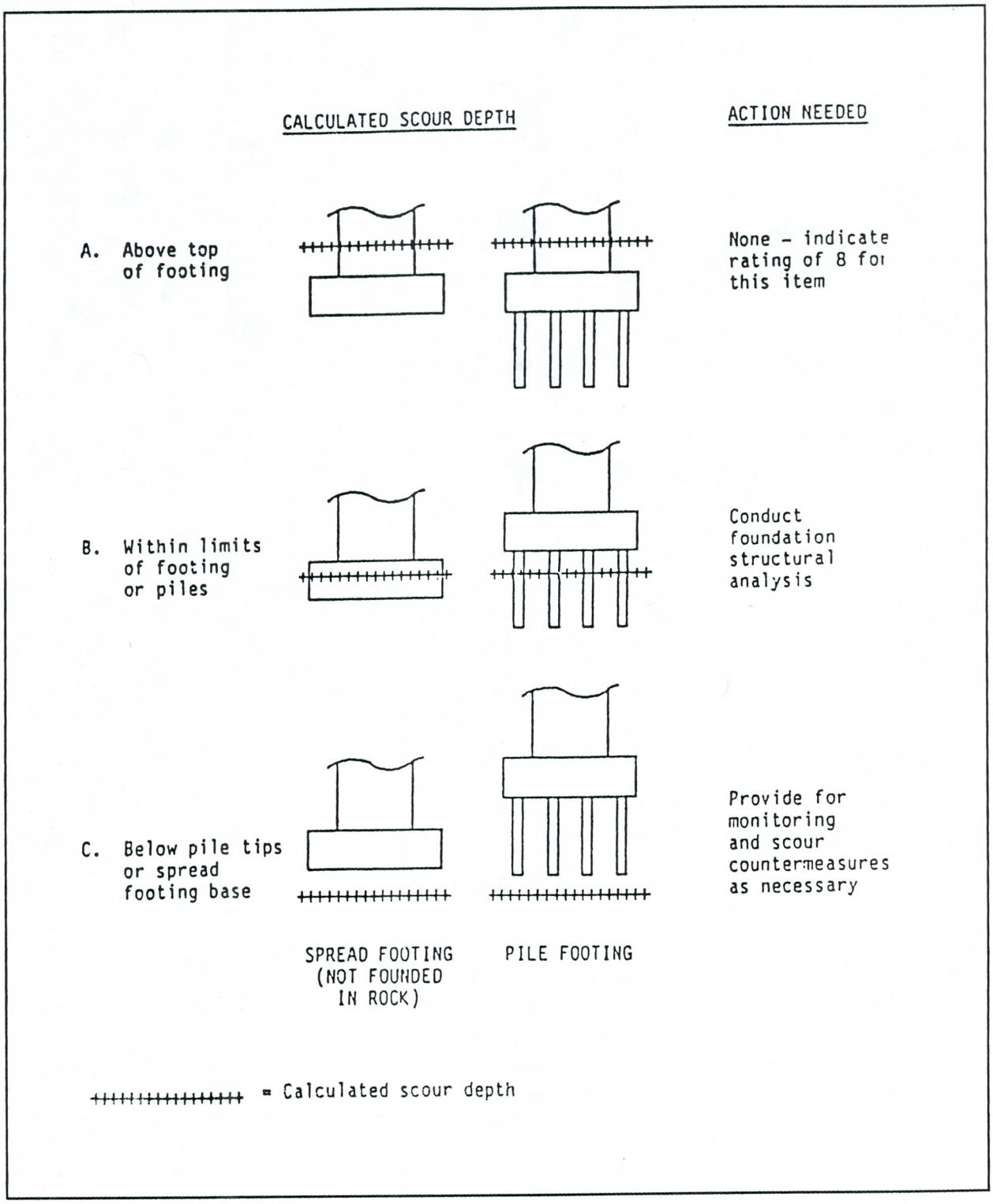
Field Inspectors:

Date of Inspection: Time of Inspection:

Bridge Number _____

SCOUR INSPECTION CODING SHEET FOR ITEM 113	
Code	Description
	LOW-RISK BRIDGES
N	Bridge not over waterway.
9	Bridge foundations (including piles) well above flood water elevations.
8	Bridge foundations determined to be stable for assessed or calculated scour conditions; calculated scour is above top of footing (Example A).
7	Countermeasures have been installed to correct a previously existing problem with scour. Bridge is no longer scour critical.
5	Bridge foundations determined to be stable for calculated scour conditions; scour within limits of footing or piles (Example B).
4	Bridge foundations determined to be stable for calculated scour conditions; field review indicates action is required to protect exposed piles from effects of additional erosion and corrosion.
	SCOUR-CRITICAL BRIDGES
3	Bridge is scour critical; bridge foundations determined to be unstable for calculated scour conditions: - scour within limits of footing or piles (Example B) - scour below spread footing base or pile tips (Example C)
2	Bridge is scour critical; field review indicates that extensive scour has occurred at a bridge foundation. Immediate action is required to provide scour countermeasures.
1	Bridges is scour critical; field review indicates that failure of piers/abutments is imminent. Bridge is closed to traffic.
0	Bridge is scour critical. Bridge has failed and is closed to traffic.
	SCOUR SUSCEPTIBLE BRIDGES
6	Scour calculation/evaluation has not been made.
	OTHER
U	Bridge with "unknown" foundation that has not been evaluated for scour. Since risk cannot be determined, flag for monitoring during flood events and, if appropriate, closure.
T	Bridge over "tidal" waters that has not been evaluated for scour, but considered low risk. Bridge will be monitored with regular inspection cycle and with appropriate underwater inspections. ("Unknown" foundations in "tidal" waters should be coded U.)

Bridge Number _____



EXAMPLES FOR CODING GUIDE ITEM 113-SCOUR CRITICAL BRIDGES

D. Use of Scour Inspection Forms.

1. Office review.

   a. Compile data and review previous inspection reports prior to site visit (see Section IC, above).

   b. If scour evaluation (T 5140.23) has been completed on bridge, enter results in Part 1, Scour Inspection Summary Sheet.

   c. Enter previous coding for NBIS items 60, 61, 71, and 113 in Part 3, Scour Inspection Summary Sheet.

   d. Sketch/copy bridge plan and profile and previous cross section data on Scour Inspection Cross Section Sheet.

   e. Complete sections of Scour Inspection Office/Field Review Report where information is available from office records.

2. Field inspection.

   a. Visit site and inspect the bridge and upstream and downstream conditions. Flow directions should be sketched, signs of aggradation or degradation noted, properties of bed and bank materials estimated or measured, and location and implications of activities impacting the bridge reach should be recorded in the appropriate sections of the Scour Inspection Office/Field Review Report. **Soundings should be taken by leadline, probing, or sonic device and plotted on the cross section sheet for comparison with previous cross sections**.

   b. Evidence of Scour - Part 1, Scour Inspection Office/Field Review Report summarizes conditions <u>visible</u> at the bridge that could support an immediate scour-critical rating.

   c. Abutments - Part 2 Scour Inspection Office/Field Review Report indicates abutment type and conditions at the <u>worst</u> abutment.

      i. Structural information on the abutments will normally be derived from office records (source of data).

ii. For concrete box culvert, indicate as structure type. No further foundation information is required.

iii. Embedment determined from Design Plans, As-Builts, or Pile Driving Records.

iv. Exposure determined from cross section plot, soundings during inspection, or visual inspection. Report exposure due to scour or stream instability.

v. Location of abutment with respect to bank is a strong indication of potential contraction scour problems.

vi. Report type of protection and condition at the abutment.

d. Pier - Part 3 Scour Inspection Office/Field Review Report indicates pier type and conditions at the typical or worst pier.

i. Structural information on piers can be derived from office records or measurements in the field (source of data).

ii. Report width and estimate length for solid web pier or pile bent.

iii. A large angle of attack indicates a potential for significant scour.

iv. Embedment determined from Design Plans, As-Builts, or Pile Driving Records.

v. Exposure determined from cross section plot, soundings during inspection, or visual inspection. Report exposure due to scour or stream instability.

vi. Report type of protection and condition at the typical or worst pier.

e. Channel Lateral Stability - Part 4 Scour Inspection Office/Field Review Report summarizes channel lateral stability factors and countermeasures visible in the field (see HEC-20 and Lesson 2).

f. Channel vertical stability - Part 5 Scour Inspection Office/Field Review Report summarizes channel vertical stability factors visible in the field and/or determined from cross section plots (see HEC-20 and Lesson 2).

i. Exposed footings, piles or pile caps indicate active ongoing scour and should also be reported in Part 1.

ii. Overbank flow, presence of a relief bridge(s) and roadway overtopping can influence contraction scour. Estimate lateral dimension of overbank.

iii. Bridge overtopping is indication of increased scour due to pressure flow.

iv. Long-term aggradation or degradation is usually inferred from comparing sequential cross section plots.

v. Bed material type may indicate relative resistance to erosion or the potential for channel armoring.

g. Overall Stream Stability - Part 6 Scour Inspection Office/Field Review Report provides a summary of stream stability factors. The stream stability factors figure should be completed with this section by circling the appropriate factors. This figure provides a visual aid in evaluating specific factors for this and other sections (see HEC-20 and Lesson 2).

i. Location on an alluvial fan indicates a potential for rapid stream channel shifts (avulsions).

ii. A dam located upstream from the bridge could indicate a potential for long-term degradation.

iii. A dam located downstream from the bridge (i.e., the bridge is in the reservoir pool) could indicate a potential for long-term aggradation.

iv. Instream sand and gravel mining in the bridge reach could indicate a potential for sediment "starvation" and long-term degradation.

v. A head cut (abrupt drop in channel slope) below the bridge could indicate potentially serious sediment imbalance and rapid degradation.

vi. A diversion above the bridge could upset the balance of water and sediment in the bridge reach.

vii. Other factors in this section are summarized on the stream stability figure (see Lesson 2).

h. Other Considerations - Part 7 Scour Inspection Office/Field Review Report includes sediment and watershed conditions that could influence scour and stream stability.

i. Sediment transport and armoring conditions influence the severity of scour.

ii. Watershed conditions indicate the hydrologic characteristics of the basin.

iii. Location of tributaries could influence the water surface elevation or the balance of water and sediment in the bridge reach.

iv. In-channel or overbank vegetative conditions indicate the relative resistance to flow (Manning's n).

i. Tidal Waterways - Part 8 Scour Inspection Office/Field Review Report summarizes observed tidal characteristics.

i. Tidal influence can be established if flow reversal occurs on a coastal stream or inferred from the presence of tide marsh vegetation.

ii. Normal tidal range can usually be estimated by high water marks on the bridge or other structures.

iii. Storm surge range or potential for wind set up can often be determined by discussion with local residents, fishermen or boaters.

j. Additional Comments - Part 9 Scour Inspection Office/Field Review Report includes a standard set of photographs and remarks on any unusual conditions or features observed.

i. It is good practice to repeat a standard set of photographs at each site visit.

ii. These should include a photo of the bridge number to identify the set, a panorama from the bridge looking (1) upstream, (2) downstream, and views of the (3) upstream, and (4) downstream face of the bridge.

iii. Comparison of repeated, photographs is particularly useful in detecting progressive stream instability problems.

iv. Conditions at the time of inspection assist a reviewer in interpreting the results of the field inspection.

v. Surface stream velocity (riverine or tidal) can be estimated by the time of travel of a float over a known (or estimated) distance.

vi. Flow depth can be estimated when soundings are taken to provide cross section data.

vii. A high water mark provides an indication of the severity of past flood or storm surge conditions. A debris line, stain line, or even historic marker (e.g., paint marker on bridge or building with note "1937 flood") can provide an estimate of historic events.

k. Remarks: any other unusual or significant conditions should be noted here or on a continuation sheet.

l. The date, time, and names of the field inspector(s) should be entered for the record.

3. Scour rating and coding.

a. **Following completion of the Scour Inspection Office/Field Review form, the new cross section data (soundings) are plotted on the Scour Inspection Cross Section sheet.**

b. The results of the office review and field inspection are summarized in Part 2 of the Scour Inspection Summary Sheet, including:

i. Scour Status - scour critical, scour susceptible or low risk.

ii. Tidal conditions.

iii. Status of Foundation - known or unknown.

iv. Reasons for rating are summarized as "bullet items" and compared with any previous scour vulnerability rating (Part 1) and changes noted.

c. Based on the scour vulnerability rating (see Guidelines in Section E, below), the Scour Inspection Coding Sheet (Item 113) can be completed. **Note: a major change in Item 113 coding requires corrective action including reevaluation by an interdisciplinary engineering team**.

d. Following Item 113 Coding, the coding for Items 60, 61, and 71 can be reviewed and changes made, as necessary. Results are summarized in Part 3 - Scour Inspection Summary sheet. **Again, a major change in a scour-related coding item may require evaluation by a qualified interdisciplinary team**.

e. Recommendations and follow-up actions required are indicated in Part 4 - Scour Inspection Summary sheet.

Remember - the inspector establishes a condition rating only. If a detailed scour analysis is required, it must be performed by a qualified interdisciplinary team.

E. Guidelines for Scour Vulnerability Rating.

1. The Scour Inspection Office/Field Review Report provides a standardized format for the inspection of bridge scour. The form represents a simple qualitative evaluation of physical characteristics and structural features which are considered important in the evaluation of bridge scour, in accordance with the guidelines contained in FHWA HEC-18 and HEC-20. It is intended to serve as a format for the office review and provide direction in the field inspection and data collection.

2. Since the site visit provides a one time inspection of site conditions, it is important that the inspector pay special attention to the potential scour associated with high flow or severe storm conditions. If there is concern for potential scour during storm events or particular tidal conditions, then additional analysis, and/or countermeasures should be recommended.

3. The report is arranged to guide the inspector through a standard scour inspection process. In this regard, several areas of the form allow alternative choices in each of the categories. These areas should be appropriately marked or circled in the field for further evaluation in the office. The scope of the qualitative analysis is designed to formulate an informed opinion of scour vulnerability based on available site-specific data and good engineering judgment.

4. Certain areas of the form should adhere to specific guidelines for conformance with the basic intent of the evaluation. Countermeasures identified on the form are representative of recommendations of the inspector. If scour monitoring is specified as a countermeasure, this may require installation of a device designed to continuously or periodically measure scour. If inspections are recommended as a countermeasure, the frequency should be specified (i.e., during routine bridge inspections, frequent seasonal inspections, or inspections made following storm events or tidal surges).

5. The Scour Vulnerability Rating for the bridge was developed to establish a qualitative rating system to enable the inspector to formulate an informed site specific opinion and as a basis for Item 113 coding. The rating is divided into five general classifications as outlined below.

Category	Rating
Scour Critical	Yes or No
Scour Susceptible	Yes or No
Low Risk	Yes or No
Tidal	Yes or No
Unknown Foundations	Known or Unknown

6. Guidelines for these ratings are as follows:

Note that it is not intended that numerical values be assigned to these guidelines. The inspector must <u>use</u> <u>judgment</u> in applying the standard forms and these guidelines in developing a scour vulnerability rating and coding the bridge for scour and stream instability. One single factor, if sufficiently serious, could result in a scour-critical rating (e.g., evidence of structural damage due to scour). A combination of factors could also result in a scour-critical rating (e.g., spread footings on erodible material in an actively degrading channel). Generally, consideration of a combination of factors will establish the rating.

SCOUR CRITICAL:

- Evidence of structural damage due to scour
- Aggressive stream or tidal waterway (high velocity, steep slope, deep flow)
- Exposed footing in erodible material
- Exposed piles with unknown or insufficient embedment
- Loss of abutment protection or pier riprap
- Needs countermeasures immediately
- Actively degrading channel

SCOUR SUSCEPTIBLE:

- Aggressive stream or tidal waterway
- Foundations are spread footings on erodible soil, shallow piles, or embedment unknown
- Tidal flows have high velocity (surface velocity > 0.9 m/s) and large tidal amplitude (> 0.6 m)
- Bed material is easily eroded
- Evidence of scour and/or degradation
- Scour is below top of footing
- Large angle of attack (> 10°)
- No countermeasures or countermeasures in poor condition
- Significant overbank flow (> 50m)
- Possibility of bridge overtopping (potential for pressure flow)

LOW RISK:

- Stream is not aggressive or other factors mitigate high velocity
- Foundation on piles of known embedment or in bedrock
- Stream aggrading or stable
- Pile foundations are deep
- Cross section stable and no evidence of scour
- Tidal flows have low velocity and range
- Countermeasures are in good condition
- Little or no possibility of overtopping bridge
- Foundations designed using current technology
- Channel heavily vegetated
- Little or no overbank flow

UNKNOWN FOUNDATIONS

- No record of foundation type (i.e., spread footing vs. piles) or condition of foundation or pile embedment is unknown

7. Scour expert system.

An ongoing National Cooperative Highway Research Program (NCHRP) project is developing a scour inspection expert system to guide and assist in scour and stream stability inspections. In the near future, it may be possible to complete much of what is presented as the Office/Field Review Report using a laptop computer.

HEC-20

Glossary of Terms

GLOSSARY

abrasion:	Removal of streambank material due to entrained sediment, ice, or debris rubbing against the bank.
afflux:	Backwater, the increase in water surface elevation upstream of a bridge relative to the elevation occurring under natural conditions.
aggradation:	General and progressive buildup of the longitudinal profile of a channel bed due to sediment deposition.
alluvial channel:	Channel wholly in alluvium; no bedrock is exposed in channel at low flow or likely to be exposed by erosion.
alluvial fan:	A fan-shaped deposit of material at the place where a stream issues from a narrow valley of high slope onto a plain or broad valley of low slope. An alluvial cone is made up of the finer materials suspended in flow while a debris cone is a mixture of all sizes and kinds of materials.
alluvial stream:	A stream which has formed its channel in cohesive or noncohesive materials that have been and can be transported by the stream.
alluvium:	Unconsolidated material deposited by water.
alternating bars:	Elongated deposits found alternately near the right and left banks of a channel.
anabranch:	Individual channel of an anabranched stream.
anabranched stream:	A stream whose flow is divided at normal and lower stages by large islands or, more rarely, by large bars; individual islands or bars are wider than about three times water width; channels are more widely and distinctly separated than in a braided stream.
apron:	Protective material placed on a streambed to resist scour.
apron, launching:	An apron designed to settle and protect the side slopes of a scour hole after settlement.
armor:	Surfacing of channel bed, banks, or embankment slope to resist erosion and scour.
armoring:	(a) Natural process whereby an erosion-resistant layer of relatively large particles is formed on a streambed due to the removal of finer particles by streamflow; (b) placement of a covering to resist erosion.
articulated concrete mass:	Rigid concrete slabs which can move without separating as scour occurs; usually hinged together with corrosion-resistant wire fasteners; primarily placed for lower bank protection.
average velocity:	Velocity at a given cross section determined by dividing discharge by cross-sectional area.
avulsion:	A sudden change in the channel course that usually occurs when a stream breaks through its banks; usually associated with a flood or a catastrophic event.

backwater:	The increase in water surface elevation relative to the elevation occurring under natural channel and floodplain conditions. It is induced by a bridge or other structure that obstructs or constricts the free flow of water in a channel.
backwater area:	The low-lying lands adjacent to a stream that may become flooded due to backwater.
bank:	The side slopes of a channel between which the flow is normally confined.
bank, left (right):	The side of a channel as viewed in a downstream direction.
bank full discharge:	Discharge that, on the average, fills a channel to the point of overflowing.
bank protecting:	Engineering works for the purpose of protecting streambanks from erosion.
bank revetment:	Erosion-resistant materials placed directly on a streambank to protect the bank from erosion.
bar:	An elongated deposit of alluvium within a channel, not permanently vegetated.
base floodplain:	The floodplain associated with the flood with a 100-year recurrence interval.
bed:	The bottom of a channel bounded by banks.
bed form:	A recognizable relief feature on the bed of a channel, such as a ripple, dune, plane bed, antidune, or bar. They are a consequence of the interaction between hydraulic forces (boundary shear stress) and the sedimentary bed.
bed layer:	A flow layer, several grain diameters thick (usually two) immediately above the bed.
bed load:	Sediment that is transported in a stream by rolling, sliding, or skipping along the bed or very close to it; considered to be within the bed layer.
bed load discharge (or bed load)	The quantity of bed load passing a cross section of a stream in a unit of time.
bed material:	Material found on the bed of a stream (May be transported as bed load or in suspension).
bedrock:	The solid rock exposed at the surface of the earth or overlain by soils and unconsolidated material.
bed shear (tractive force):	The force per unit area exerted by a fluid flowing past a boundary.
boulder:	A rock fragment whose diameter is greater than 250 mm.
braid:	A subordinate channel of a braided stream.
braided stream:	A stream whose flow is divided at normal stage by small mid-channel bars or small islands; the individual width of bars and islands is less than about three times water width; braided stream has the aspect of a single large channel within which are subordinate channels.

bridge opening:	The cross-sectional area beneath a bridge that is available for conveyance of water.
bridge waterway:	The area of a bridge opening available for flow, as measured below a specified stage and normal to the principal direction of flow.
bulkhead:	A vertical, or near vertical, wall that supports a bank or an embankment; also may serve to protect against erosion.
caving:	The collapse of a bank caused by undermining due to the action of flowing water. Also, the falling in of the concave side of a bend of which the curvature is changing.
channel:	The bed and banks that confine the surface flow of a stream.
channelization:	Straightening or deepening of a natural channel by artificial cutoffs, grading, flow-control measures, or diversion of flow into a man-made channel.
cellular-block mattress:	Interconnected concrete blocks with regular cavities placed directly on a streambank or filter to resist erosion. The cavities can permit bank drainage and the growth of vegetation where synthetic filter fabric is not used between the mattress and bank.
channel diversion:	The removal of flows by natural or artificial means from a natural length of channel.
channel pattern:	The aspect of a stream channel in plan view, with particular reference to the degree of sinuosity, braiding, anabranching.
channel process:	Behavior of a channel with respect to shifting, erosion and sedimentation.
check dam:	A low dam or weir across a channel used to control stage or degradation.
choking (of flow):	Excessive constriction of flow which may cause severe backwater effect.
clay:	A particle whose diameter is in the range of 0.00024 to 0.004 mm.
clay plug:	A cutoff meander bend filled with fine grained cohesive sediments.
cobble:	A fragment of rock whose diameter is in the range of 64 to 250 mm.
concrete revetment:	Plain or reinforced concrete slabs placed on the channel bed to protect it from erosion.
confluence:	The junction of two or more streams.
constriction:	A natural or artificial control section, such as a bridge crossing, channel reach or dam, with limited flow capacity in which the upstream water surface elevation is related to discharge.
contact load:	Sediment particles that roll or slide along in almost continuous contact with the streambed.
contraction:	The effect of channel constriction on flow streamlines.

countermeasure:	A measure intended to prevent, delay or reduce the severity of hydraulic problems.
contraction scour:	Scour in a channel or on a floodplain that is not localized at a pier, abutment, or other obstruction to flow. In a channel, contraction scour results from the contraction of streamlines and usually affects all or most of the channel width.
Coriolis force:	The inertial force caused by the Earth's rotation that deflects a moving body to the right in the Northern Hemisphere.
crib:	A frame structure filled with earth or stone ballast, designed to reduce energy and to deflect streamflow away from a bank or embankment.
critical shear stress:	The minimum amount of shear stress required to initiate soil particle motion.
crossing:	The relatively short and shallow reach of a stream between bends; also crossover.
cross section:	A section normal to the trend of a channel.
current:	Water flowing through a channel.
cut bank:	The concave wall of a meandering stream.
cutoff:	(a) A direct channel, either natural or artificial, connecting two points on a stream, thereby shortening the original length of the channel and increasing its slope; (b) A natural or artificial channel which develops across the neck of a meander loop.
cutoff wall:	A wall, usually of sheet piling or concrete, that extends down to scour-resistant material or below the expected scour depth.
daily discharge:	Discharge averaged over one day.
debris:	Floating or submerged material, such as logs or trash, transported by a stream.
deflector:	Alternative term of "spur."
degradation (bed):	A general and progressive lowering of the channel bed due to erosion.
density of water-sediment mixture:	Bulk density (mass per unit volume), including both water and sediment.
depth of scour:	The vertical distance a streambed is lowered by scour below a reference elevation.
design flow (design flood):	The discharge that is selected as the basis for the design or evaluation of a hydraulic structure.
dike:	An impermeable linear structure for the control or containment of overbank flow. A dike-trending parallel with a streambank differs from a levee in that it extends for a much shorter distance along the bank, and it may be surrounded by water during floods.

dike (groin, spur, jetty):	A structure extending from a bank into a channel that is designed to: (a) reduce the stream velocity as the current passes through the dike, thus encouraging sediment deposition along the bank (permeable dike); or (b) deflect erosive current away from the streambank (impermeable dike).
dominant discharge:	(a) The discharge which is of sufficient magnitude and frequency to have a dominating effect in determining the characteristics and size of the stream course, channel, and bed; (b) That discharge which determines the principal dimensions and characteristics of a natural channel. The dominant formative discharge depends on the maximum and mean discharge, duration of flow, and flood frequency. For hydraulic geometry relationships, it is taken to be the bankfull discharge which has a return period of approximately 1.5 years in many natural channels.
drift:	Alternative term for "debris."
eddy current:	A vortex-type motion of a fluid flowing contrary to the main current, such as the circular water movement that occurs when the main flow becomes separated from the bank.
entrenched stream:	Stream cut into bedrock or consolidated deposits.
ephemeral stream:	A stream or reach of stream that does not flow for parts of the year. As used here, the term includes intermittent streams with flow less than perennial.
erosion:	Displacement of soil particles on the land surface due to water or wind action.
erosion control matting:	Fibrous matting (e.g., jute, paper, etc.) placed or sprayed on a streambank for the purpose of resisting erosion or providing temporary stabilization until vegetation is established.
estuary:	Tidal reach at the mouth of a stream.
fabric mattress:	Grout-filled mattress used for streambank protection.
fetch:	The area in which waves are generated by wind having a rather constant direction and speed; sometimes used synonymously with fetch length.
fetch length:	The horizontal distance (in the direction of the wind) over which wind generates waves and wind setup.
fill slope:	Side or end slope of an earth fill embankment.
filter:	Layer of fabric, sand, gravel, or graded rock placed between bank revetment and soil for the following purposes: (1) to prevent the soil from moving through the revetment by piping, extrusion, or erosion; (2) to prevent the revetment from sinking into the soil; and (3) to permit natural seepage from the streambank, thus preventing the buildup of excessive hydrostatic pressure.
filter blanket:	A layer of graded sand and gravel laid between fine-grained material and riprap to serve as a filter.
filter cloth:	Geosynthetic fabric that serves the same purpose as a granular filter blanket.

fine sediment load (wash load):	That part of the total sediment load that is composed of particle sizes finer than those represented in the bed. Normally, the fine-sediment load is finer than 0.062 mm for sand-bed channel. Silts, clays and sand could be considered wash load in coarse gravel and cobble-bed channels.
flanking:	Erosion resulting from streamflow between the bank and the landward end of a countermeasure for stream stabilization.
flashy stream:	Stream characterized by rapidly rising and falling stages, as indicated by a sharply peaked hydrograph. Most flashy streams are ephemeral, but some are perennial.
floodplain:	A nearly flat, alluvial lowland bordering a stream, that is subject to inundation by floods.
flow-control structure:	A structure either within or outside a channel that acts as a countermeasure by controlling the direction, depth, or velocity of flowing water.
flow slide:	Saturated soil materials which behave more like a liquid than a solid. A flow slide on a channel bank can result in a bank failure.
fluvial geomorphology:	The science dealing with the profiles and planforms of streams and rivers.
Froude Number:	A dimensionless number that represents the ratio of inertial to gravitational forces. High Froude Numbers can be indicative of high flow velocity and the potential for scour.
gabion:	A basket or compartmentalized rectangular container made of wire mesh, filled with cobbles or other rock of suitable size. Gabions are flexible and permeable blocks with which flow- and erosion-control structures can be built.
geomorphology/ morphology:	That science that deals with the form of the Earth, the general configuration of its surface, and the changes that take place due to erosion of the primary elements and in the buildup of erosional debris.
grade-control structure (sill, check dam):	Structure placed bank to bank across a stream channel (usually with its central axis perpendicular to flow) for the purpose of controlling bed slope and preventing scour or headcutting.
graded stream:	A geomorphic term used for streams that have apparently achieved a state of equilibrium between the rate of sediment transport and the rate of sediment supply throughout long reaches. Any change which alters the state of equilibrium can lead to action by the stream to reestablish equilibrium.
gravel:	A rock fragment whose diameter ranges from 2 to 64 mm.
groin:	A structure built from the bank of a stream in a direction transverse to the current. Many names are given to this structure, the most common being "spur," "spur dike," "transverse dike," "jetty," etc. Groins may be permeable, semi-permeable, or impermeable.
guide bank:	Preferred term for spur dike.

hardpoint:	A streambank protection structure whereby "soft" or erodible materials are removed from a bank and replaced by stone or compacted clay. Some hard points protrude a short distance into the channel to direct erosive currents away from the bank. Hard points also occur naturally along streambanks as passing currents remove erodible materials leaving nonerodible materials exposed.
headcutting:	Channel degradation associated with abrupt changes in the bed elevation (headcut) that generally migrates in an upstream direction.
helical flow:	Three-dimensional movement of water particles along a spiral path in the general direction of flow. These secondary-type currents are of most significance as flow passes through a bend; their net effect is to remove soil particles from the cut bank and deposit this material on the point bar.
hydraulic radius:	The cross-sectional area of a stream divided by its wetted perimeter.
hydraulic problem:	An effect of streamflow, tidal flow, or wave action such that the integrity of the highway facility is destroyed, damaged, or endangered.
incised reach:	A stretch of stream with an incised channel that only rarely overflows its banks.
incised stream:	A stream which has cut its channel through the bed of the valley floor, as opposed to one flowing on a floodplain.
island:	A permanently vegetated area, emergent at normal stage, that divides the flow of a stream. Islands originate by establishment of vegetation on a bar, by channel avulsion, or at the junction of minor tributary with a larger stream.
jack:	A device for flow control and protection of banks against lateral erosion consisting of three mutually perpendicular arms rigidly fixed at the center. Kellner jacks are made of steel struts strung with wire, and concrete jacks are made of reinforced concrete beams.
jack field:	Rows of jacks tied together with cables, some rows generally parallel with the banks and some perpendicular thereto or at an angle. Jack fields may be placed outside or within a channel.
jetty:	(a) An obstruction built of piles, rock, or other material extending from a bank into a stream, so placed as to induce scouring or bank building, or to protect against erosion; (b) A similar obstruction to influence stream, lake, or tidal currents, or to protect a harbor.
lateral erosion:	Erosion in which the removal of material is extended in a lateral direction, as contrasted with degradation and scour in a vertical direction.
launching:	Release of undercut material (stone riprap, rubble, slag, etc.) downslope or into a scoured area.
levee:	An embankment, generally landward of top bank, that confines flow during high-water periods, thus preventing overflow into lowlands.
littoral drift:	The transport of material along a shoreline.
local scour:	Scour in a channel or on a floodplain that is localized at a pier, abutment, or other obstruction to flow.

lower bank:	That portion of a streambank having an elevation less than the mean water level of the stream.
mattress:	A blanket or revetment materials interwoven or otherwise lashed together and placed to cover an area subject to scour.
meander or full meander:	A meander in a river consists of two consecutive loops, one flowing clockwise and the other counter-clockwise.
meander belt:	The distance between lines drawn tangent to the extreme limits of successive fully developed meanders.
meander length:	The distance along a stream between corresponding points at the extreme limits of successive fully developed meanders.
meander loop:	An individual loop of a meandering or sinuous stream lying between inflection points with adjoining loops.
meander ratio:	The ratio of meander width to meander length.
meander width:	The amplitude of swing of a fully developed meander measured from midstream to midstream.
meandering channel:	A channel exhibiting a characteristic process of bank erosion and point bar deposition associated with systematically shifting meanders.
meander scrolls:	Low, concentric ridges and swales on a floodplain, marking the successive positions of former meander loops.
meandering stream:	A stream having a sinuosity greater than some arbitrary value. The term also implies a moderate degree of pattern symmetry, imparted by regularity of size and repetition of meander loops.
median diameter:	The particle diameter of the 50th percentile point on a size distribution curve such that half of the particles (by weight, number, or volume) are larger and half are smaller.
mid-channel bar:	A bar lacking permanent vegetal cover that divides the flow in a channel at normal stage.
middle bank:	The portion of a streambank having an elevation approximately the same as that of the mean water level of the stream.
migration:	Change in position of a channel by lateral erosion of one bank and simultaneous accretion of the opposite bank.
natural levee:	A low ridge formed along streambanks during floods by deposition that slopes gently away from the channel banks.
nominal sediment	Equivalent spherical diameter of a hypothetical sphere of the same volume as a given stone.
nonalluvial channel:	A channel whose boundary is completely in bedrock.
normal stage:	The water stage prevailing during the greater part of the year.

overbank flow:	Water movement overtop bank either due to stream stage or to inland surface water runoff.
oxbow:	The abandoned bow-shaped or horseshoe-shaped reach of a former meander loop that remains after a stream cuts a new, shorter channel across the narrow neck between closely approaching bends of a meander.
perennial stream:	A stream or reach of a stream that flows continuously for all or most of the year.
phreatic line:	The upper boundary of the seepage water surface landward of a streambank.
pile dike:	A type of permeable structure for the protection of banks against caving; consists of a cluster of piles driven into the stream, braced and lashed together.
piping:	Removal of soil material through subsurface flow of seepage water that develops channels or "pipes" within the soil bank.
point bar:	An alluvial deposit of sand or gravel lacking permanent vegetal cover occurring in a channel at the inside of a meander loop, usually somewhat downstream from the apex of the loop.
poised stream (stable stream):	A stream which, as a whole, maintains its slopes, depths, and channel dimensions without any noticeable raising or lowering of its bed. Such condition may be temporary from a geological point of view, but for practical engineering purposes, the stream may be considered stable.
quarry-run stone:	Stone as received from a quarry without regard to gradation requirements.
railbank protection:	A type of countermeasure composed of rock-filled wire fabric supported by steel rails or posts driven into streambed.
rapid drawdown:	Lowering the water against a bank more quickly than the bank can drain without becoming unstable.
reach:	A segment of stream length that is arbitrarily bounded for purposes of study.
regime:	The condition of a stream or its channel as regards stability. A stream is in regime if its channel has reached a stable form as a result of its flow characteristics.
regime channel:	Alluvial channel that has attained, more or less, a state of equilibrium with respect to erosion and deposition.
regime change:	A change in channel characteristics resulting from such things as changes in imposed flows, sediment loads or slope.
regime formula:	A formula relating stable alluvial channel dimensions or slope to discharge and sediment characteristics.
reinforced-earth bulkhead:	A retaining structure consisting of vertical panels and attached to reinforcing elements embedded in compacted backfill for supporting a streambank.

reinforced revetment:	A streambank protection method consisting of a continuous stone toe-fill along the base of a bank slope with intermittent fillets of stone placed perpendicular to the toe and extending back into the natural bank.
retard (retarder structure):	A permeable or impermeable linear structure in a channel parallel with the bank and usually at the toe of the bank, intended to reduce flow velocity, induce deposition, or deflect flow from the bank.
revetment:	Rigid or flexible armor placed to inhibit scour and lateral erosion. (See bank revetment).
riffle:	A natural, shallow flow area extending across a streambed in which the surface of flowing water is broken by waves or ripples. Typically, riffles alternate with pools along the length of a stream channel.
riparian:	Pertaining to anything connected with or adjacent to the banks of a stream.
riprap:	In the restricted sense, layer or facing of broken rock or concrete dumped or placed to protect a structure or embankment from erosion; also the broken rock or concrete suitable for such use. Riprap has also been applied to almost all kinds of armor, including wire-enclosed riprap, grouted riprap, sacked concrete, and concrete slabs.
river training:	Engineering works with or without the construction of embankment, built along a stream or reach of stream to direct or to lead the flow into a prescribed channel. Also, any structure configuration constructed in a stream or placed on, adjacent to, or in the vicinity of a streambank that is intended to deflect currents, induce sediment deposition, induce scour, or in some other way alter the flow and sediment regimes of the stream.
rock-and-wire mattress:	A flat or cylindrical wire cage or basket filled with stone or other suitable material and placed as protection against erosion.
roughness coefficient:	Numerical measure of the frictional resistance to flow in a channel, as in the Manning's or Chezy's formulas.
rubble:	Rough, irregular fragments of materials of random size used to retard erosion. The fragments may consist of broken concrete slabs, masonry, or other suitable refuse.
sack revetment:	Sacks (e.g., burlap, paper, or nylon) filled with mortar, concrete, sand, stone or other available material used as protection against erosion.
saltation load:	Sediment bounced along the streambed by energy, turbulence of flow, and by other moving particles.
sand:	A rock fragment whose diameter is in the range of 0.062 to 2.0 mm.
scour:	Erosion due to flowing water; usually considered as being localized as opposed to general bed degradation.
scoured depth:	Total depth of the water from water surface to a scoured bed level (compare with "depth of scour").

sediment or fluvial sediment:	Fragmental material transported, suspended, or deposited by water.
sediment concentration:	Weight or volume of sediment relative to quantity of transporting or suspending fluid or fluid-sediment mixture.
sediment discharge:	The quantity of sediment that is carried past any cross section of a stream in a unit of time. Discharge may be limited to certain sizes of sediment or to a specific part of the cross section.
sediment load:	Amount of sediment being moved by a stream.
sediment yield:	The total sediment outflow from a watershed or a drainage area at a point of reference and in a specified time period. This outflow is equal to the sediment discharge from the drainage area.
seepage:	The slow movement of water through small cracks and pores of the bank material.
seiche:	Long-period oscillation of a lake or similar body of water.
set-up:	Raising of water level due to wind action.
shallow water (for waves):	Water of such a depth that waves are noticeably affected by bottom conditions; customarily, water shallower than half the wavelength.
shoal:	A submerged sand bank. A shoal results from natural deposition on a streambed which has resisted all erosion; thus, the water is of necessity compelled to pass over it.
sill:	(a) A structure built under water, across the deep pools of a stream with the aim of changing the depth of the stream; (b) A low structure built across an effluent stream, diversion channel or outlet to reduce flow or prevent flow until the main stream stage reaches the crest of the structure.
silt:	A particle whose diameter is in the range of 0.004 to 0.062 mm.
sinuosity:	The ratio between the thalweg length and the valley length of a sinuous stream.
slope (of channel or stream):	Fall per unit length along the channel centerline.
slope protection:	Any measure such as riprap, paving, vegetation, revetment, brush or other material intended to protect a slope from erosion, slipping or caving, or to withstand external hydraulic pressure.
sloughing:	Sliding of overlying material; same ultimate effect as caving, but usually occurs when a bank or an underlying stratum is saturated.
slope-area method:	A method of estimating unmeasured flood discharges in a uniform channel reach using observed high-water levels.
slump:	A sudden slip or collapse of a bank, generally in the vertical direction and confined to a short distance, probably due to the substratum being washed out or having become unable to bear the weight above it.

soil-cement:	A designed mixture of soil and Portland cement compacted at a proper water content to form a blanket or structure that can resist erosion.
sorting:	Progressive reduction of size (or weight) of particles of the load carried down a stream.
spill-through abutment:	A bridge abutment having a fill slope on the streamward side.
spur:	A permeable or impermeable linear structure that projects into a channel from the bank to alter flow direction, induce deposition, or reduce flow velocity along the bank.
spur dike/guide bank:	A dike extending upstream from the approach embankment at either or both sides of the bridge opening. Guide banks may also extend downstream from the bridge.
stable channel:	A condition that exists when a stream has a bed slope and cross section which allows its channel to transport the water and sediment delivered from the upstream watershed without aggradation, degradation, or bank erosion (a graded stream).
stage:	Water-surface elevation of a stream with respect to a reference elevation.
stone riprap:	Natural cobbles, boulders, or rock dumped or placed as protection against erosion.
stream:	A body of water that may range in size from a large river to a small rill flowing in a channel. By extension, the term is sometimes applied to a natural channel or drainage course formed by flowing water whether it is occupied by water or not.
streambank erosion:	Removal of soil particles or a mass of particles from a bank surface due primarily to water action. Other factors such as weathering, ice and debris abrasion, chemical reactions, and land use changes may also directly or indirectly lead to bank erosion.
streambank failure:	Sudden collapse of a bank due to an unstable condition such as due to removal of material at the toe of the bank by scour.
streambank protection:	Any technique used to prevent erosion or failure of a streambank.
suspended sediment discharge (suspended load):	The quantity of sediment passing through a stream cross section in a unit of time suspended by the turbulence of flow.

sub-bed material:	Material underlying that portion of the streambed which is subject to direct action of the flow.
submeander:	A small meander contained within the banks of a perennial stream channel. These are caused by relatively low discharges after the flood has subsided.
subcritical, supercritical flow:	Open channel flow conditions with Froude Number less than and greater than unity, respectively.
tetrahedron:	Component of river-training works made of six steel or concrete struts fabricated in the shape of a pyramid.
tetrapod:	Bank protection component of precast concrete consisting of four legs joined at a central joint, with each leg making an angle of 109.5° with the other three.
thalweg:	The line extending down a channel that follows the lowest elevation of the bed.
tieback:	Structure placed between revetment and bank to prevent flanking.
timber or brush mattress:	A revetment made of brush, poles, logs, or lumber interwoven or otherwise lashed together. The completed mattress is then placed on the bank of a stream and weighted with ballast.
toe of bank:	That portion of a stream cross section where the lower bank terminates and the channel bottom or the opposite lower bank begins.
toe protection:	Loose stones laid or dumped at the toe of an embankment, groin, etc., or masonry or concrete wall built at the junction of the bank and the bed in channels or at extremities of hydraulic structures to counteract erosion.
total sediment load (or total load):	The sum of suspended load and bed load or the sum of bed material load and wash load of a stream.
trench-fill revetment:	Stone, concrete, or masonry material placed in a trench dug behind and parallel to an eroding streambank. When the erosive action of the stream reaches the trench, the material placed in the trench armors the bank and thus retards further erosion.
turbulence:	Motion of fluids in which local velocities and pressures fluctuate irregularly in a random manner as opposed to laminar flow where all particles of the fluid move in distinct and separate lines.
uniform flow:	Flow of constant cross section and velocity through a reach of channel at a given instant. Both the energy slope and the water slope are equal to the bed slope under conditions of uniform flow.
unit discharge:	Discharge per unit width (may be average over a cross section, or local at a point).
unit shear force (shear stress):	The force or drag developed at the channel bed by flowing water. For uniform flow, this force is equal to a component of the gravity force acting in a direction parallel to the channel bed on a unit wetted area. Usually in units of stress, Pa (N/m^2).
unsteady flow:	Flow of variable cross section and velocity with respect to time.

upper bank:	The portion of a streambank having an elevation greater than the average water level of the stream.
velocity:	The rate of motion in a fluid on a stream or of the objects or particles transported therein, usually expressed in m/s.
velocity-weighted sediment concentration:	The dry weight of sediment discharged through a cross section during unit time.
wandering channel:	A channel exhibiting a more or less non-systematic process of channel shifting, erosion and deposition, with no definite meanders or braided pattern.
wandering thalweg:	A thalweg whose position in the channel shifts during floods and typically serves as an inset channel that conveys all or most of the stream flow at normal or lower stages.
wash load:	Suspended material of very small size (generally clays and colloids) originating primarily from erosion on the land slopes of the drainage area and present to a negligible degree in the bed itself.
waterway opening width (area):	Width (area) of bridge opening at (below) a specified stage, measured normal to the principal direction of flow.
weephole:	A hole in an impermeable wall or revetment to relieve the neutral stress or pore pressure in the soil.
windrow revetment:	A row of stone placed landward of the top of an eroding streambank. As the windrow is undercut, the stone is launched downslope, thus armoring the bank.
wire mesh:	Wire woven to form a mesh; where used as an integral part of a countermeasure, openings are of suitable size and shape to enclose rock or broken concrete or to function on fence-like spurs and retards.

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Appendix F

Scour Measuring and Monitoring Equipment

APPENDIX F

Scour Measuring and Monitoring Equipment

F.1. INTRODUCTION

As discussed in chapter 7, scour monitoring is considered to be a suitable countermeasure for scour. Scour monitoring is differentiated from inspection in that monitoring generally implies the determination of the bed elevation at the time that scour is occurring. Although simple in concept, the ability to monitor scour during floods is inhibited by high flow depths and velocities, turbidity, floating debris, turbulence and ice. It is because of the adverse environment which exists in and around bridge piers and abutments during high flows (when maximum scour generally occurs) that, until recently, there were few instruments and techniques available to measure scour. Recent research has resulted in development of mobile and fixed instrumentation for measuring scour during flood flows.[78] This instrumentation has proven useful for monitoring scour and inspecting general streambed conditions for routine maintenance and scour evaluations.

Past techniques to measure scour have focused on manual mechanical methods such as using a graduated rod to probe the scour hole, using a cable and lead weight, or similar techniques. Sonic fathometers have also been used with varying degrees of success. In a few notable cases divers have attempted to probe the scour holes around bridge piers at high water, but these few attempts have proven to be extremely dangerous given the nature of the turbulence around a bridge foundation, particularly during flood flows.

Geophysical tools and techniques have also been adapted or are being developed to measure and monitor scour at bridge piers. Some of these techniques can be employed as post–flood inspection methods to determine maximum scour depths after floods.

The following text discusses some of the most promising techniques and instruments which are, or may be available in the future to monitor and measure scour at bridge piers and abutments. In the following paragraphs, techniques for either mobile or fixed installation scour monitoring devices are discussed. Then various geophysical tools which have been, or could be utilized for scour monitoring or post–flood inspection are described.

F.2. MOBILE INSTRUMENTATION

Mobile instrumentation comprises all instrumentation which can be brought to a bridge site to measure scour at both flood and normal conditions. Typically, these instruments are deployed on a boat, unmanned floating equipment platforms, from the bridge, or other means to sense the bed along and around the bridge piers and abutments. In some cases, sonic transducers have been attached to sounding weights and suspended over the bridge rail using a portable crane and winch arrangement.

Mobile instrumentation can range from a simple black and white fathometer (typically used by fishermen) to ground penetrating radar, tuned transducers, color fathometers, or other geophysical techniques. Cable and a lead weight similar to that used for stream gaging are also used for scour measurement. More recently, two– and three–dimensional sonic fathometers which can produce three–dimensional images have become available.

An advantage of these techniques is that since the instrumentation is mobile, the equipment can be used to service many bridges within a highway department's region. This feature makes mobile instruments particularly useful to inspectors involved in the 2– and 5–year bridge inspection cycle. Many state DOTs have been using black and white fathometers for developing cross section surveys of the bridge waterway area as well as for scour monitoring.

Disadvantages of mobile instrumentation relate to the inherent dangers and difficulties involved in collecting data, particularly during flood flows. In addition, some of the instrumentation requires technically qualified personnel to operate and maintain the device and interpret data.

F.3. FIXED INSTRUMENTATION

Scour monitoring equipment can be deployed in a fixed installation mode to provide a scour monitoring capability. In a typical installation, an instrument combined with a method to either manually or digitally record scour data can be installed on or near a bridge pier or abutment to provide scour monitoring or measuring. These instruments include low–cost or more sophisticated sonic fathometers, sounding rods, or buried or driven rods.

Due to the wide variety of pier and abutment geometries, and because of the variability in river geometry, flow conditions, bed material, and other characteristics of highway crossings, no single fixed instrumentation type will be applicable to meet the needs of all cases. Rather, there is a need to have a variety of fixed instrumentation to meet the needs of the varied conditions found at bridges.

F.3.1. Sounding Rods

In the context of fixed scour monitoring equipment, the use of sounding rods encompasses methods whereby a rod resting on the bed is allowed to slide vertically as scour develops. The rod is constrained to vertical movement as scour develops by means of a sleeve or other method which will orient the sounding rod directly above the scour hole but will allow the rod to move vertically. Scour depths can be determined either manually or by using data logging techniques. One such instrument, known as the Brisco Monitor (use of trade names is for identification purposes only), is currently commercially available. This instrument measures scour by measuring the length of cable, which is attached to the top of the sounding rod, unwound from a spool in the data recording enclosure.

Sounding rods, such as the one described above, can be used as scour monitoring devices, however these instruments are limited by the expected ultimate depth of scour, and subsequently, the length of rod required to accurately track the development of scour. As the rod length increases, the weight of the rod bearing on the bed material also increases. The entire weight of the rod must be supported by the bed material of the scour hole. A footplate attached to the end of the sounding rod must be of sufficient size to prevent the rod from penetrating the bed.

F.3.2. Sonic Fathometers

Sonic fathometers can be attached to the bridge pier or abutment to monitor scour. Currently there are several research organizations experimenting with and field testing these types of instrumentation. For example, the USGS has instrumented several bridges using both a simple "fish finder" fathometers and more sophisticated commercial sonic fathometers. The Virginia Transportation Research Council has installed multiple transducers on a bridge south of Richmond, VA. This installation is equipped with data logging and telemetering capability. Under an NCHRP project (Project 21–3) to develop scour instrumentation, Ayres Associates (formerly Resource Consultants & Engineers, Fort Collins, Colorado) have reported successful operation of a "fish finder" type sonic fathometer linked to a datalogger at several tidal and riverine bridges.[78]

The bridge deck serviceable sonic fathometer developed under NCHRP Project 21–3 uses a low–cost commercial sonic fathometer to monitor and measure scour. The transducer for this device is mounted in a housing which is designed to slide freely inside a conduit mounted to the bridge pier or abutment and aimed at the location where scour is anticipated to occur (see figure F.1). The transducer is inserted from the bridge deck into the conduit and snapped into place in the end of the conduit. This design allows for the servicing or replacement of the transducer without the need for scaffolds, inspection cranes, or divers.

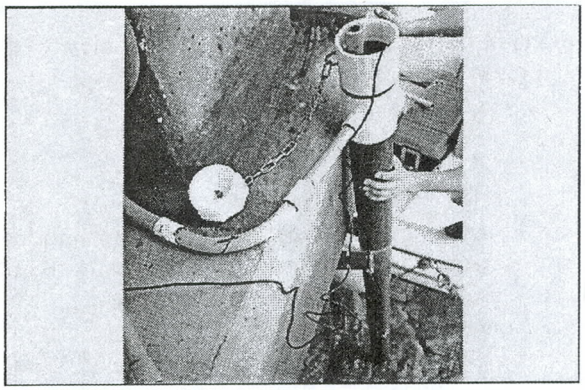


Figure F.1. Sonic instrument on Johns Pass bridge, Florida.

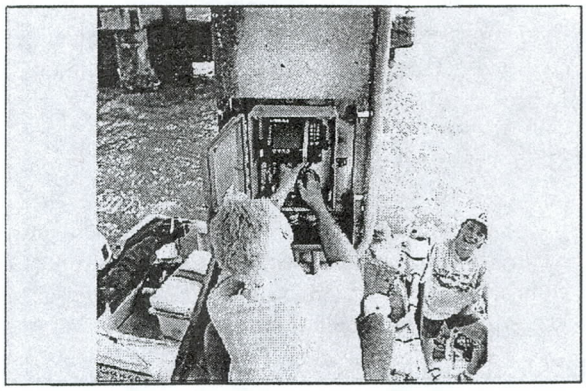


Figure F.2. Sonic datalogger on Johns Pass bridge, Florida.

Scour data are obtained and recorded by a specially designed datalogger (figure F.2) connected to the sonic fathometer. In this way, a time–stamped record of the scour and fill process can be recorded, stored, and retrieved for future analysis. Electrical power is provided by a battery and solar panel. This system also lends itself to telemetry of scour data from a remote site.

During field tests conducted by RCE from 1992–1995, this instrument performed well, documenting the scour and fill process. Installations have included bridges on the South Platte River in Colorado, the Rio Grande in New Mexico, as well as bridges in Texas and New York. The most challenging installation was on the Johns Pass bridge at a deep (14 m), aggressive tidal inlet on Florida's Gulf Coast. This instrument has proven to be extremely reliable in a very hostile tidal environment over a two–year period. The only significant limitation of this low–cost sonic system is its vulnerability to blockage when ice or debris accumulates on the bridge pier below the transducer. High velocity, sediment laden flows have not proven to be a limitation in deploying this device.

F.3.3. Buried or Driven Rod Instrumentation

This class of devices encompasses all instrumentation which could be mounted in or attached to a vertical support which is either buried or driven into the channel bed at the location where scour is expected to occur. By sensing the channel bed/water interface, the progression of scour can be monitored or measured.

Under NCHRP Project 21–3, a simple magnetic sliding collar was tested in the laboratory and deployed to field sites in response to the need to develop a simple device that might progress through the development stages quickly. This device consists of an open collar, which is free to slide over a small–diameter stainless steel pipe. A large bar magnet is mounted on the collar (figure F.3). The pipe can be driven into the streambed at a location where scour is expected to occur. The pipe (which can be made and shipped in sections) is driven into the bed using either manual, pneumatic, or other mechanical methods. Scour is determined by inserting a magnetic sensor (probe) mounted at the end of a graduated cable into the support pipe or extension conduit from the bridge deck. When the sensor is close to the magnet on the collar, an audible signal (buzzer) is heard at the bridge deck.

Magnetic sliding collar devices have been installed in the field at many locations since 1992, including Colorado, Minnesota, Michigan, New Mexico, and Texas (see figure F.4). Test sites have included a variety of geomorphic and geologic conditions and have exposed the instruments to impact from both ice and debris. The instrument is best suited to smaller bridges and shallower flow depths (3–5 m). Of the eight instruments tested in the field, only one has been destroyed by debris impact.

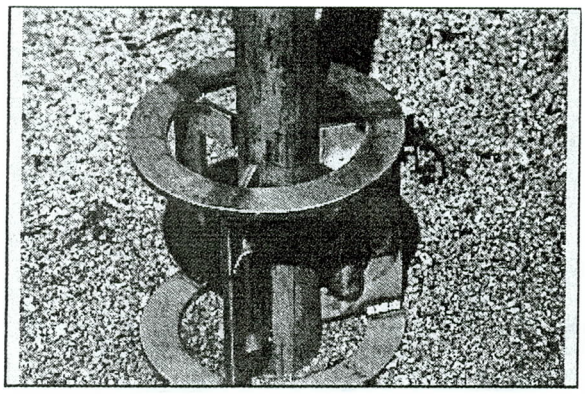


Figure F.3. Sliding collar instrument.

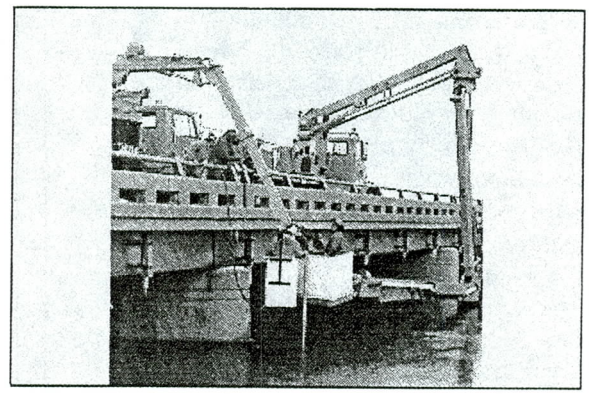


Figure F.4. Instrument installation, Michigan DOT.

The design of this instrument is simple and it is easy to install and operate. The device can be fabricated in a variety of lengths and can be installed using bends to route the extension conduit from the top of the stainless steel pipe to the bridge deck. Thus, the instrument can be fastened closely to most bridge piers and abutments to protect the instrument from debris and ice impact. In sand–bed streams, the instrument can be driven into the bed using a modified fence post–type driver. In more cohesive streambeds, the instrument can be installed by using a pneumatic post driver. At this time, only manual determination of the scour depth can be made using the probe and buzzer. However, a multiple magnetic sensor array, which can be used to upgrade existing field sites, has been designed and will be tested in the near future. This multiple sensor array allows linking the instrument to a datalogger so that the time history of scour can be automatically logged. It will also permit installing the instrument flush with the streambed, eliminating the vulnerable section of the extension conduit on the face of the bridge pier.

F.4. GEOPHYSICAL TOOLS

After a flood, the stream velocity decreases which may result in the sediment being redeposited in the scour hole, (referred to as infilling). Since this material often has a different density than the adjacent unscoured material, the true extent of scour can be measured by determining the interface where the density change occurs. Methods for determining this interface includes standard penetration testing, cone penetrometer exploration, and geophysical techniques. While standard penetration testing is accurate it is expensive, time consuming and does not provide a continuous profile. Less expensive geophysical methods are available, which will provide continuous subsurface profiles by providing information on the physical properties of the substrate.

The three geophysical tools which have been used to measure scour after infilling occurs are: ground penetrating radar, tuned transducer, and color fathometer. Each of these methods has its advantages and limitations. However, if applied properly, they can yield meaningful data in a very short period of time. The U.S. Geological Survey in cooperation with the Federal Highway Administration has used each of these tools to study the extent of scour and the findings are documented in a report entitled "The Use of Surface Geophysical Methods in Studying River Bed Scour." The following descriptions are taken from that report by S.R. Gorin and F.P. Haeni of the U.S. Geological Survey.

F.4.1. Ground Penetrating Radar

Ground penetrating radar (GPR) can be used to obtain high resolution, continuous, subsurface profiles on land or in relatively shallow water (less than 7.6 m). This device transmits short, 80 to 800 MHz electromagnetic pulses into the subsurface and measures the two way travel time for the signal to return to the subsurface and measures the two way travel time for the signal to return to the receiver. When the electromagnetic energy reaches an interface between two materials with differing physical properties, a portion of the energy is reflected back to the surface, while some of it is attenuated and a portion is transmitted to

deeper layers. The penetration depth of GPR is dependent upon the electrical properties of the material through which the signal is transmitted and the frequency of the signal transmitted. Highly conductive (low resistivity) materials such as clay materials severely attenuate radar signals. Similarly, sediments saturated with or overlain by salt water will yield poor radar results. Fresh water also attenuates the radar signal and limits the use of radar to sites with less than 7.6 m of water. The lower frequency signals yield better penetration and reduced resolution, whereas higher frequency signals yield higher resolution and less penetration. Ground penetrating radar systems which include a transmitter, receiver, and antenna and a high density tape recorder and player for storage of records cost approximately $50,000.

Figure F.5 shows a cross section generated by a ground penetrating radar signal upstream of a bridge pier. The scour hole is approximately 2.1 m deeper than the river bottom base level and 18 to 21 m wide. Two different infilled layers can be observed at this location. The apparent thickness of the infilled material at the center of the hole is 0.9 m to the first interface and 1.8 m to the second interface.

F.4.2. Tuned Transducer

The tuned transducer and the color fathometer are both seismic systems which operate through the transmission and reception of acoustic waves. A portion of the seismic signal is reflected back to the surface when there is a change in acoustical impedance between two layers. The major variable which separates these two devices from the standard fathometer is the frequency. The tuned transducer and color fathometer have lower frequency signals (20 KHz) which yield better penetration at the expense of resolution. High frequency fathometers (200 KHz) have good resolution with little or no penetration. In fine grained materials, up to 30.5 m of penetration can be obtained with a 3 to 7 KHz transducer, while in coarser material subsurface penetration may be limited to a meter. The tuned transducer system cost approximately $25,000.

Figure F.5 shows a cross section record provided by a 14 KHz tuned transducer. This is the same location as the GPR record in figure F.4. The record shows 1.8 m of infilled material. The two layers which could be seen on the radar record are not evident on the tuned transducer record.

F.4.3. Color Fathometer

The color fathometer is a variable frequency seismic system that digitizes the reflected signal and displays a color image on a monitor. This system measures the reflected signal in decibels and it distinguishes between different interfaces by assigning color changes to a given degree of decibel change. Since decibel changes in the reflected signal are related to density, porosity and median grain size, the instrument is able to identify and define shallow interfaces in the subsurface. Where infilling has occurred, the soft material is easily penetrated and shown to have low reflectivity as opposed to denser materials which have high reflectivity. Typically, the materials which have a low reflectivity are assigned the "cool" colors such as blue and green while the denser material is represented by the "hot" colors such as red and orange. Since the data is displayed on a color monitor, a hard copy is not readily available; however, it can be stored on a cassette tape for playback and processing. The U.S. Geological Survey is presently working on developing a computer program to process the color fathometer record in order to remove some of the extraneous and undesirable signals which make interpretation more difficult.

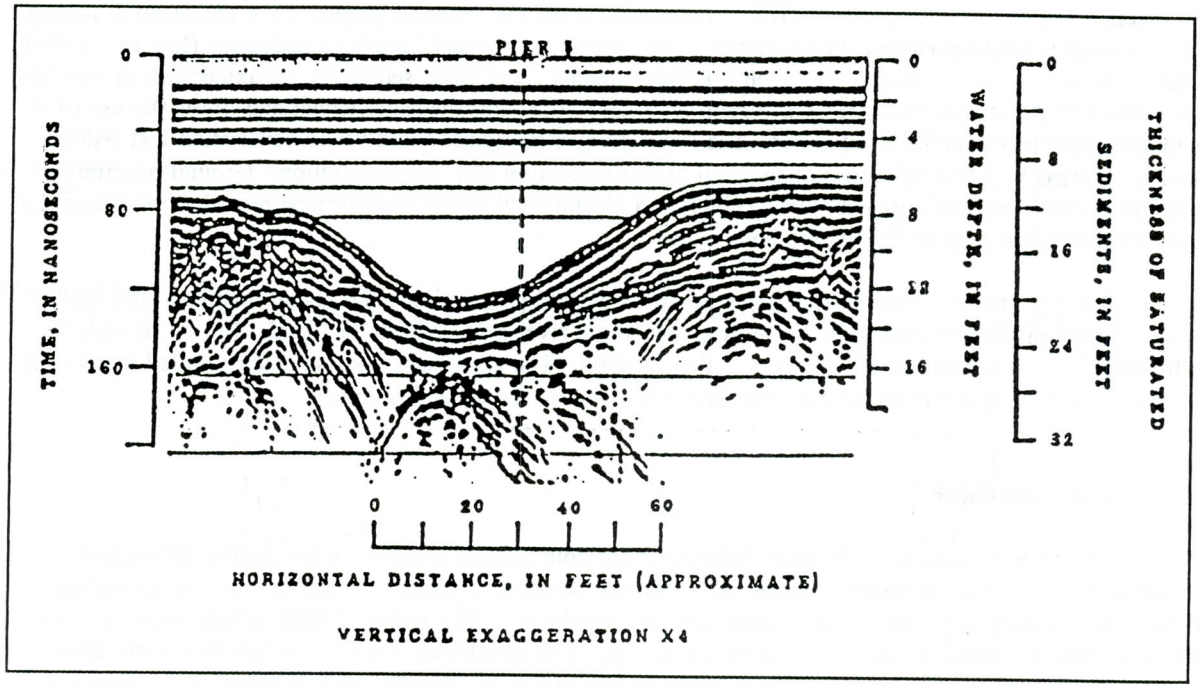


Figure F.5. Example of ground penetrating radon.

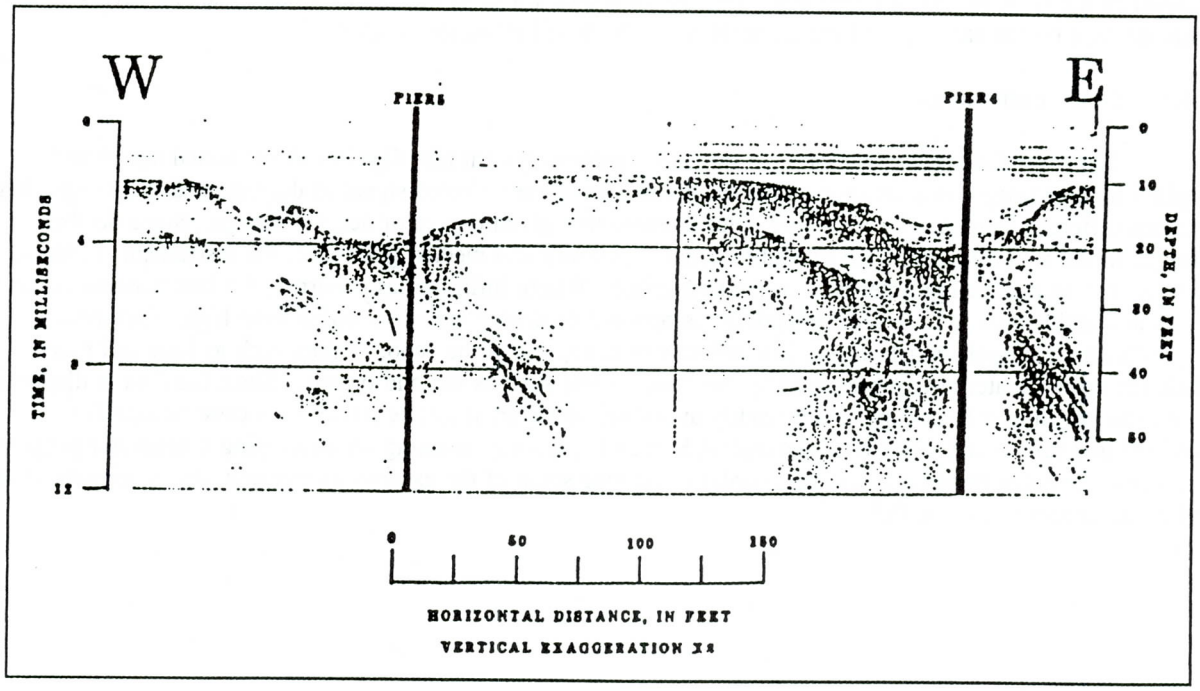


Figure F.6. Example of 14 KHz tuned transducer.

F.4.4. Black and White Fathometer

Even though the black and white fathometer is unable to penetrate the channel except in very soft mud, it is still considered an excellent tool for defining the channel bottom. The graphic recorder is easy to use, reasonably inexpensive and will provide an accurate bottom profile very quickly. Also when used in conjunction with the other tools, it adds a degree of certainty to the other geophysical data. A 200 KHz fathometer with graphics capabilities can be purchased for approximately $1,000.

Figure F.7 shows a cross section using a 200 KHz fathometer. This record correlates with the radar and tuned transducer record shown in figures F.5 and F.6 with the exception that the radar record was run 1.8 m further upstream.

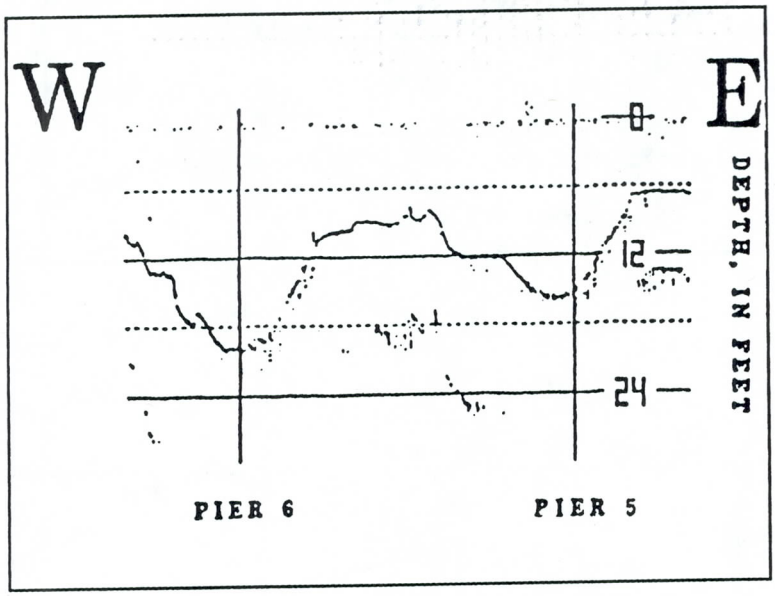


Figure F.7. Example of 200 KHz fathometer.

WORKSHOP PROBLEM SOLUTION

III. WORKSHOP PROBLEM

A. During the Field Visit a Portable Sonic Sounding Device was Used to Obtain the Following Sounding Information.

	Top of Rail to Water Surface (m)	Sounder Reading		Distance to Streambed (m)
		(ft)	(m)	
Bent 2	4.8	7.9	2.41	7.21
Bent 3	4.8	17.4	5.30	10.10
Bent 4	4.8	22.9	6.98	11.78
Bent 5	4.8	20.7	6.31	11.11
Bent 6	4.8	19.7	6.00	10.80
Bent 7	4.8	17.7	5.39	10.19
Bent 8	4.8	10.8	3.29	8.09
Bent 9	4.8	7.9	2.41	7.21
Bent 10	4.8	8.2	2.50	7.30

Plot these soundings on the Scour Inspection Cross Section Sheet.

What problems do the soundings indicate?

- **Significant scour or degradation between Bents 3, 4, and 5**
- **Some fill or aggradation at Bent 10**

What is the most likely cause of this change?

- **Channel shift**
- **Dredging or a cutoff (see aerial photo)**
- **Large flood or storm surge since last inspection (show slide - no name storm)**

While completing the soundings, you observe a high water mark stain on the piling (normal tide) about 0.5 m above the water surface. The water surface appears low in relation to bank height and the tide is going out.

You estimate the distance from the upstream face of the bridge to the downstream face to be 10.7 m. You drop an orange (biodegradable) at the upstream face and measure its travel time to the downstream face at 15.3 seconds.

What is the surface velocity?

$$V = \frac{10.7}{15.3} = 0.7 \text{ m/s}$$

While inspecting the right (north) abutment you note that the sand cement (grouted bag) slope protection reported as eroding in 1993 has not been repaired and appears to be deteriorating.

B. Using the Information Presented Above, Complete the Scour Inspection Office/Field Review Report.

Note: You can request review of slides, as needed.

SCOUR INSPECTION - SUMMARY SHEET

Bridge No.: 150032	County: Pinellas	Route: SR55(US19)	Waterway: Anclote R.

1. PREVIOUS SCOUR VULNERABILITY RATING			2. CURRENT SCOUR VULNERABILITY RATING		
a. Scour Critical	☐ YES	■ NO	a. Scour Critical	■ YES	☐ NO
Scour Susceptible	■ YES	☐ NO	Scour Susceptible	☐ YES	☐ NO
Low Risk	☐ YES	■ NO	Low Risk	☐ YES	☐ NO
Tidal	■ YES	☐ NO	Tidal	■ YES	☐ NO
Foundation	■ Known	☐ Unknown	Foundation	■ Known	☐ Unknown

b. Reasons for vulnerability rating:

- Bridge susceptible to storm surge and riverine flood flows
- Easily eroded bed material
- Bridge encroaches on channel with significant overbank flow
- Countermeasures at north abutment in poor condition
- Large angle of attack

b. Reasons for vulnerability rating or changes:

- Observed scour in erodable bed
- Shallow embedment (~ 3m)
- Left abutment encroaches on channel
- High angle of attack
- Significant overbank flow
- Long term degradation
- Possible high stage flows
- Countermeasures in poor condition (north abutment)
- Erosion on upstream right bank

3. CODING

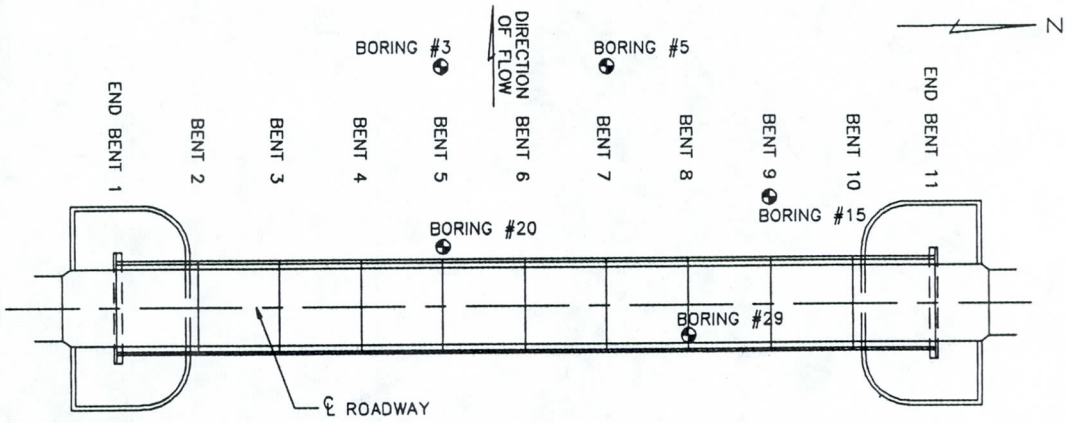
	Previous	Recommended*
Item 113 Scour	6	2
Item 60 Substructure	7	4
Item 61 Channel & Channel Protection	8	3
Item 71 Waterway Adequacy	8	8

*Major change in condition rating requires corrective action (see 4)

4. RECOMMENDATIONS/ACTION

- ☐ No further action required
- ■ Qualified interdisciplinary team conduct foundation scour and structural analysis
- ☐ Underwater or follow up inspection required
- ■ Notification
- ■ Plan of Action
- ■ Monitor (specify frequency/criteria (after high flow)
- ■ Install scour countermeasures (fixed scour monitor)
- ■ Repair existing countermeasures (Riprap north abutment)
- ■ Close Bridge or Contingency Plan

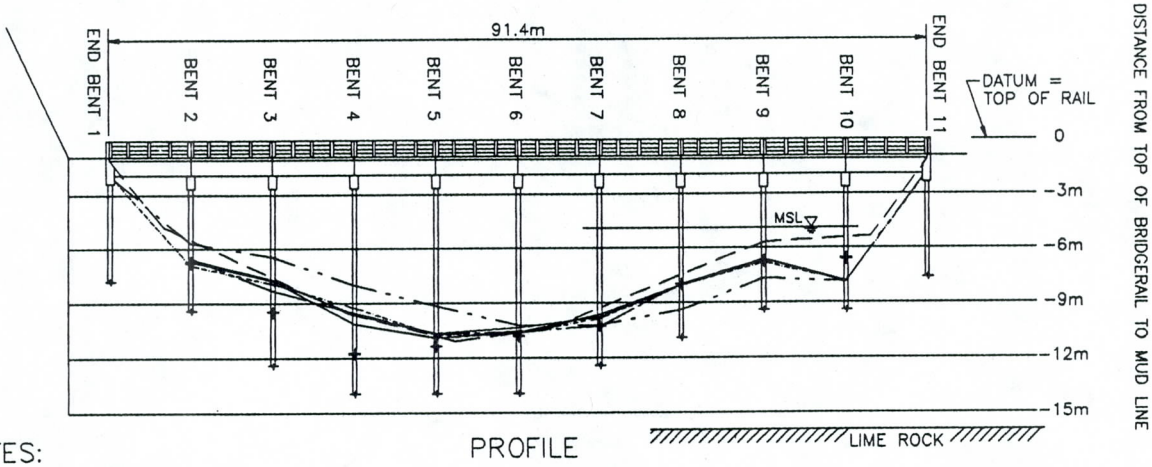
SCOUR INSPECTION CROSS SECTION SHEET



PLAN

STRATA DATA

1 – SILT & SAND
2 – FINE SAND & CLAY
3 – SOFT LIMESTONE
4 – HARD LIMESTONE
5 – SOFT LIMEROCK & CLAY
6 – HARD LIMEROCK
7 – SOFT CLAY
8 – SOFT WATERY CLAY
9 – VOID
10 – HARD CLAY
11 – SOFT ROCK
12 – HARD ROCK



PROFILE

NOTES:

1. DRAWING BASED ON 1969 DESIGN PLANS. (STATE PROJECT NO. 15150-3517)
2. SOIL BORING DATA BASED ON 1969 DESIGN PLANS. (STATE PROJECT NO. 15150-3517)
3. CHANNEL CROSS-SECTION TAKEN FROM LEFT SIDE OF BRIDGE.
4. 1969 MUD LINE WAS SCALED FROM THE DESIGN PLANS AND IS APPROXIMATE.

CHANNEL SOUNDING LEGEND

1993 INSPECTION REPORT
1991 INSPECTION REPORT
1989 INSPECTION REPORT
1987 INSPECTION REPORT
1986 INSPECTION REPORT
1969 DESIGN PLANS

Instructions:

(1) Office Review: Sketch plan and profile of bridge and plot previous cross sections from bridge inspection files or T 5140.23 scour evaluation.

(2) Field Review: Plot cross section (soundings) taken in field and compare with previous cross sections for indications of long-term aggradation, degradation, or local cross section changes.

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

1. SITE FIELD REVIEW

a. Evidence of Scour at Structure (Response: YES/NO or Comment)

1) Abutment Tilting / Moving In: ☐ YES ■ NO

2) Pier Rotating/Tilting ☐ YES ■ NO

3) Slopes Washing In / Sloughing: ☐ YES ■ NO

4) Scour Near Abutments / Bents: ■ YES ☐ NO

5) Loss of abutment protection or pier riprap ■ YES ☐ NO

6) Bridge Rail or Deck Sagging: ☐ YES ■ NO

7) Debris: ☐ YES ■ NO

b. Feasibility of Monitoring During High Flow

1) Rod / Pole / Weight from Deck: ☐ YES ■ NO

2) Portable Monitoring Device: ■ YES ☐ NO

3) Fixed Monitoring Device: ■ YES ☐ NO

c. Feasibility of Adding Riprap/Other Countermeasures: ■ YES ☐ NO

2. ABUTMENTS

a. Structure Type: ■ Bridge ☐ Conc. Box Culvert

b. Abutment Type: ■ Spill Through ☐ Vertical Wall ☐ Wing Walls ☐ Seawall

c. Foundation	Dimensions (L,W,D) (m)	Embedment (m)	Exposure (m)
☐ Spread Footings			
☐ Pile Caps			
■ Piles	1.5 x 1.5 x 20 (ft)	6 m	None
☐ Drilled Shaft			

Source of Data: ■ Field Review ■ Design Plans ☐ As-Builts ■ Pile Driving Records ■ Inspection Records ☐ Other

d. Location from Bank	Left (m)	Right (m)	
Set Back			
At Edge of Channel		0	
Project Into Channel	12 m		

e. Protection

1) Countermeasures: ■ Sand Cement ☐ Riprap ☐ Commercial Block ■ Grouted ☐ Seawall ☐ Guide Bank ☐ None ☐ Other

2) Condition of Countermeasures: ☐ N/A

	Good	Fair	Poor	Unknown
Left	■	☐	☐	☐
Right	☐	☐	■	☐

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

3. PIER

a. Type (Typical or Worst Pier) Bent 4

☐ Concrete Wall ■ Pile Bent ☐ Column

b. Location: ■ Channel ☐ Overbank

c. Shape: ☐ Square ■ Rounded ☐ Sharp Nose

d. Width (0.6) m Length (10.7) m

e. Flow Angle of Attack: Flood Flow (10°) Normal Flow (10°)

f.

Foundation (Worst Pier)	Dimensions (L,W,D) (m)	Embedment (m)	Exposure (m)
☐ Spread Footing			
☐ Pile Cap			
■ Piles	0.6 m	2.5 m	2.5 m
☐ Drilled Shaft			

Source of Data: ■ Field Review ■ Design Plans ☐ As-Builts ■ Pile Driving Records ■ Inspection Records ☐ Other

g. Protection:

1) Countermeasures: ☐ Sand Cement ☐ Riprap ☐ Commercial Block ☐ Grouted ☐ Seawall ■ None ☐ Other:

2) Condition of Countermeasures: ■ N/A ☐ Good ☐ Fair ☐ Poor ☐ Unknown

4. CHANNEL LATERAL STABILITY

a. Bends

1) Bridge Location: ☐ Upstream of Bend ☐ Downstream of Bend ■ In Bend

2) Channel Migration ☐ Yes ■ No

3) Countermeasures ☐ Yes ■ No Type:

b. Bank Condition:

	Upstream	Downstream	
1) Eroding	■	☐	(Erosion - upstream right bank)
2) Stable	☐	■	
3) Vegetated	■	■	
4) Seawall	☐	☐	

5) Countermeasures ☐ Yes ■ No Type:

c. Point Bar Under Bridge: ☐ Yes ■ No

d. Islands or Bars

1) Upstream ■ Yes ☐ No

2) Downstream ■ Yes ☐ No

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

5. CHANNEL VERTICAL STABILITY

a. Exposed Footing ☐ Yes ■ No ☐ Unknown

b. Exposed Piles ■ Yes ☐ No ☐ Unknown **4 m**

c. Contraction Scour (Encroachment)

1) Overbank Flow ■ Left ■ Yes ☐ No **(600 m)**
■ Right ■ Yes ☐ No **(60 m)**

2) Relief Bridge(s) ☐ Yes ■ No

3) Roadway Overtopping ☐ Yes ☐ No ☐ Unknown ■ Possible

4) Bridge Overtopping ☐ Yes ■ No ☐ Unknown ☐ Possible

d. Long Term

1) Aggradation ☐ Yes ■ No ☐ Unknown

2) Degradation ■ Yes ☐ No ☐ Unknown

e. Bed Material

■ Sand

☐ Gravel

☐ Cobbles

☐ Other **Silt (Lime Rock layer at -16 m)**

6. OVERALL STREAM STABILITY (complete attached figure)

a. Alluvial Fan ☐ Yes ■ No

b. Dam or Reservoir ☐ Yes ■ No ☐ Upstream ☐ Downstream

c. River Form: ☐ Straight ☐ Meandering ■ Braided ☐ Man Made **(Anabranched)**

d. Instream Mining / Dredging ■ Yes ☐ No **(local side channel)**

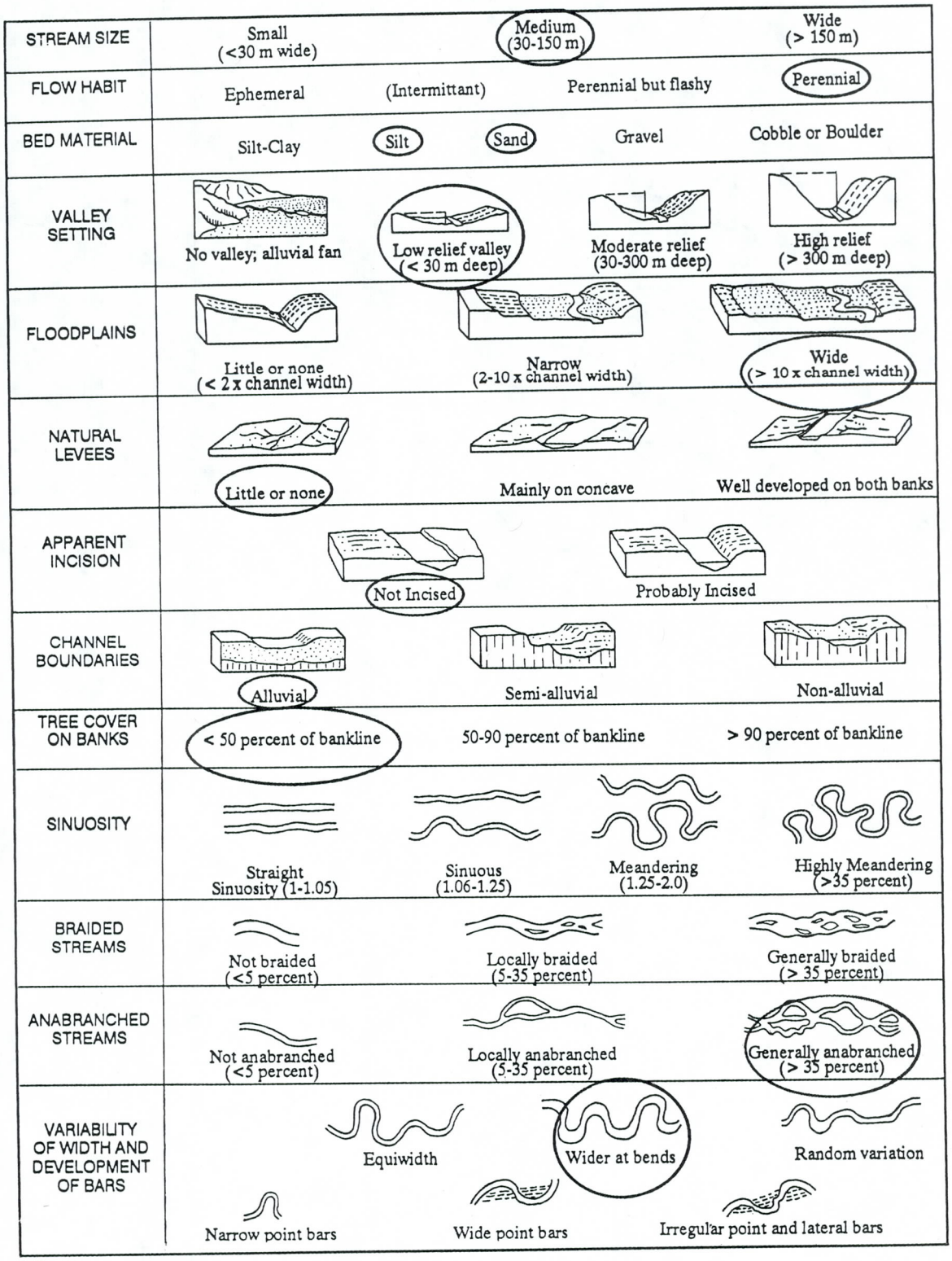
e. Headcuts (abrupt drop in channel slope) ☐ Yes ■ No

f. Diversions ☐ Yes ■ No

g. Channel Straightening ■ Yes ☐ No **(possible cutoff)**

h. Stream Size: ☐ Small (<30 m) ■ Medium (30-150 m) ☐ Large (>150 m)

i. Flow Characteristics: ☐ Ephemeral ☐ Intermittent ■ Perennial ■ Tidal



FACTORS THAT AFFECT STREAM STABILITY

SCOUR INSPECTION - OFFICE/FIELD REVIEW REPORT

7. OTHER CONSIDERATIONS

a. Sediment Transport:

1) ■ Live-Bed Condition ☐ Clear-Water Condition ☐ Unknown

2) Armored Bed ☐ Yes ■ No ☐ Unknown

b. Watershed: ☐ Agricultural ☐ Forested ■ Swamp ■ Urban

c. Tributaries ☐ Upstream ☐ Downstream ■ No Factor

d. Distance to confluence of next stream or water body - km (2.5) upstream

e. In-channel vegetation ■ None ☐ Light ☐ Heavy

f. Overbank vegetation ☐ None ☐ Light ■ Heavy

8. TIDAL WATERWAYS

a. Tidal Influence: ■ Yes ☐ No ☐ Unknown ☐ Possible

b. Tidal Features: ☐ Bay ■ Estuary ☐ Inlet ☐ Barrier Island

c. Tidal Conditions:

1) Normal Range ■ Field Observation (1 m) ☐ Tide Table

2) Storm Surge ■ Yes ☐ No

3) Seiching (wind set up) ■ Yes ☐ No

4) Distance to coast - km (1.6) Km Along Thalweg (1.6)

5) Traffic: ☐ Ship ■ Recreation ☐ Commercial ☐ Barge ☐ Intracoastal Waterway

9. ADDITIONAL COMMENTS

a. Photographs: ■ Bridge Number ■ Upstream Channel ■ Upstream Face ■ Downstream Channel ■ Downstream Face

b. Conditions at time of inspection:

1) Flow conditions (riverine) ■ Low Flow ☐ Bank Full ☐ Overbank

2) Flow conditions (tidal) ■ Low Tide ☐ Slack Tide ☐ High Tide ■ Ebb Tide ☐ Flood Tide

3) Flow velocity: Surface velocity can be estimated in the field from the time of travel of a floating object over a known distance.

$$V = \frac{\text{distance}}{\text{time}} = 0.7 \text{ m/s}$$

4) Flow depth (5) m

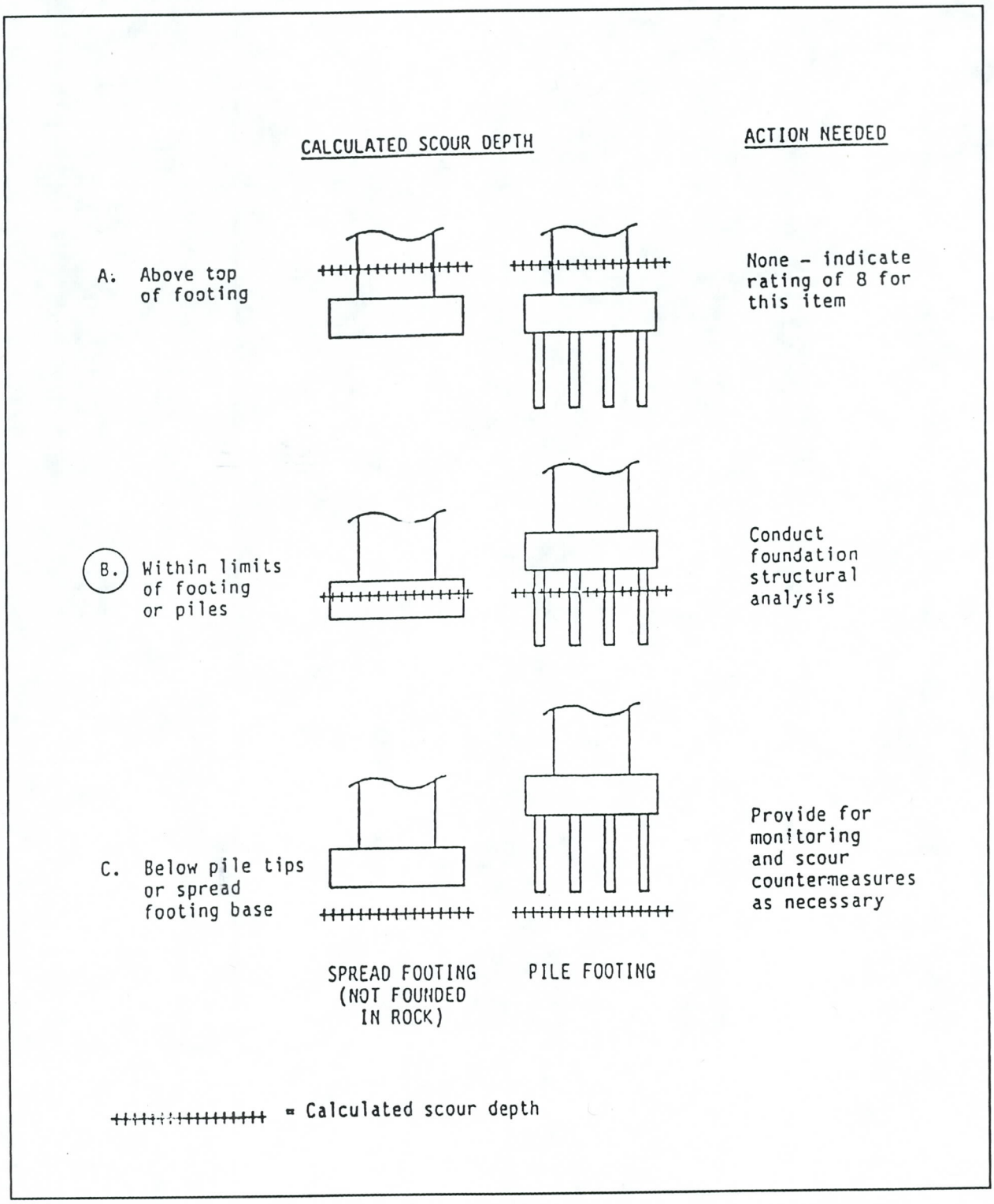
5) High water mark (0.5) m above normal flow

c. Remarks:

Field Inspectors: Instructor

Date of Inspection: Any Day Time of Inspection: Any Time

SCOUR INSPECTION CODING SHEET FOR ITEM 113	
Code	Description
	LOW-RISK BRIDGES
N	Bridge not over waterway.
9	Bridge foundations (including piles) well above flood water elevations.
8	Bridge foundations determined to be stable for assessed or calculated scour conditions; calculated scour is above top of footing (Example A).
7	Countermeasures have been installed to correct a previously existing problem with scour. Bridge is no longer scour critical.
5	Bridge foundations determined to be stable for calculated scour conditions; scour within limits of footing or piles (Example B).
4	Bridge foundations determined to be stable for calculated scour conditions; field review indicates action is required to protect exposed piles from effects of additional erosion and corrosion.
	SCOUR-CRITICAL BRIDGES
3	Bridge is scour critical; bridge foundations determined to be unstable for calculated scour conditions: - scour within limits of footing or piles (Example B) - scour below spread footing base or pile tips (Example C)
2	Bridge is scour critical; field review indicates that extensive scour has occurred at a bridge foundation. Immediate action is required to provide scour countermeasures.
1	Bridges is scour critical; field review indicates that failure of piers/abutments is imminent. Bridge is closed to traffic.
0	Bridge is scour critical. Bridge has failed and is closed to traffic.
	SCOUR SUSCEPTIBLE BRIDGES
6	Scour calculation/evaluation has not been made.
	OTHER
U	Bridge with "unknown" foundation that has not been evaluated for scour. Since risk cannot be determined, flag for monitoring during flood events and, if appropriate, closure.
T	Bridge over "tidal" waters that has not been evaluated for scour, but considered low risk. Bridge will be monitored with regular inspection cycle and with appropriate underwater inspections. ("Unknown" foundations in "tidal" waters should be coded U.)



EXAMPLES FOR CODING GUIDE ITEM 113-SCOUR CRITICAL BRIDGES

C. Using the results of the field visit as noted on the Scour Inspection Office/Field Report and the soundings taken in the field, complete Part 2 of the Scour Inspection Summary Sheet.

D. Using the Scour Inspection Coding Sheet for Item 113, determine a current scour coding.

Based on guidelines for scour vulnerability rating (Section IIE, Lesson 9) and reasons for rating as summarized in Part 2 Scour Inspection Summary Sheet, code the bridge as 2 for Item 113 (Refer also to Item 113 figure, Example B).

E. Reevaluate other NBIS coding items related to scour (Items 60, 61, and 71) and recode as appropriate.

Refer to Additional Coding Part III, Lesson 7. For Item 60 Code 4 - for "advanced scour, removal of bed material below top of footing or pile cap" seems appropriate. Could even consider Code 3. Item 61 (Channel and Channel Protection) and Item 71 (Waterway Adequacy) would not be affected for conditions given in the workshop.

F. Complete Part 4 of the Scour Inspection Summary Sheet - Recommendations/Action.

What follow-up action is required?

Item 113 changed from Code 6 to Code 2 and Item 60 changed from Code 7 to Code 4. These changes warrant having an interdisciplinary team conduct a foundation scour and structural analysis. The problem is serious enough to develop a notification plan for possible emergency action and a contingency plan for possible bridge closure.

If a Plan of Action is recommended, what are the essential elements?

- **Timely installation of temporary countermeasures (riprap)**
- **Develop a monitoring program (see below)**
- **Schedule timely design and construction of permanent countermeasures or bridge replacement**

Discuss any other observations and potential problems for this bridge as a result of your inspection for scour.

- **Bridge should be inspected after high flows or coastal storm or storm surge**
- **Bridge is a good candidate for installation of a fixed scour monitoring device**
- **Damaged north abutment slope protection should be repaired immediately**

U.S. Department
of Transportation

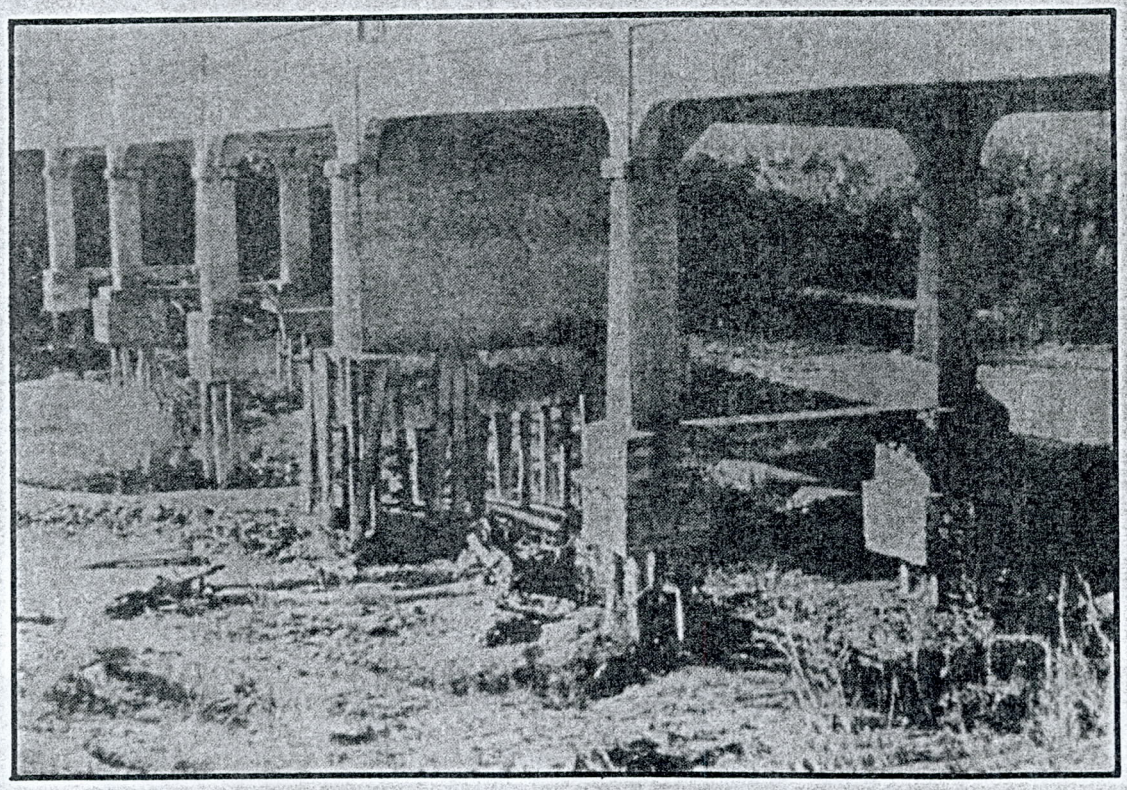
**Federal Highway
Administration**

Publication No. FHWA-HI-91-011
March 1991

NHI Course No. 13046

Stream Stability and Scour at Highway Bridges

Participant Notebook



STREAM STABILITY AND SCOUR AT HIGHWAY STRUCTURES

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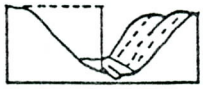
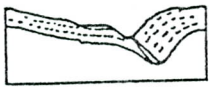
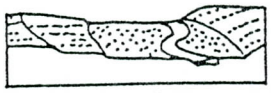
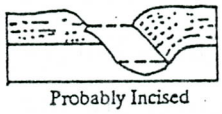
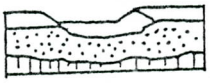
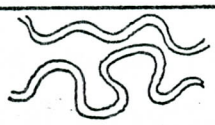
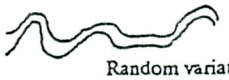
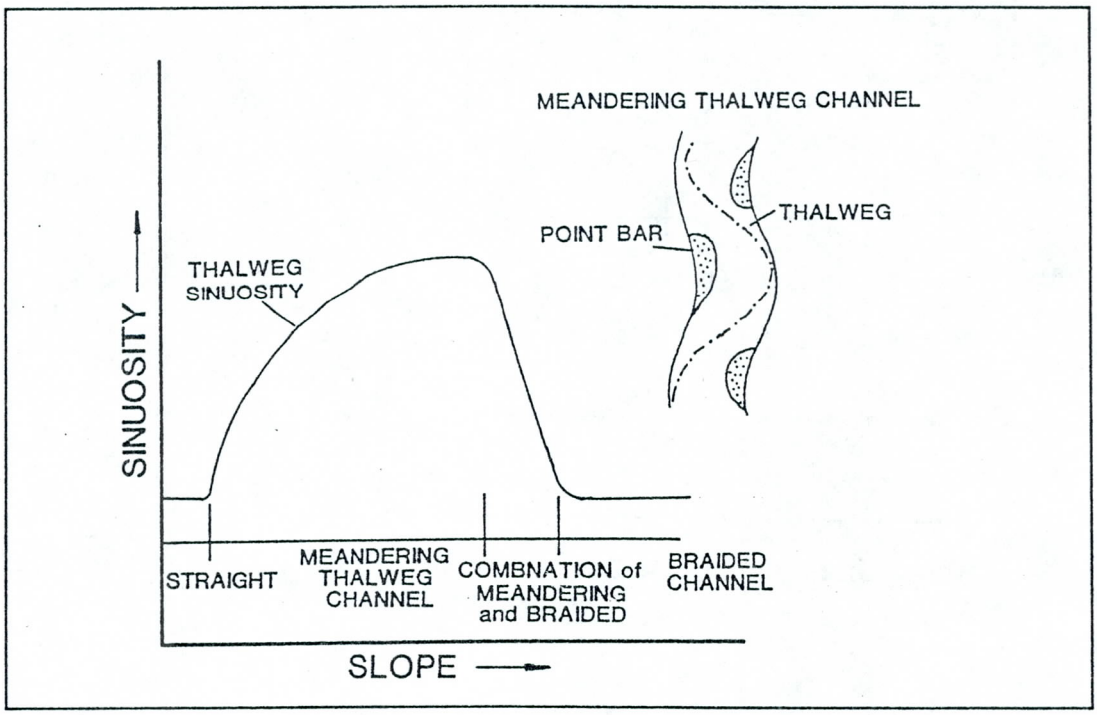
STREAM SIZE (SECT. 2.2.1)	Small (<100 ft. or 30 m wide)		Medium (100-500 ft. or 3-150 m)		Wide (>500 ft. or 150 m)
FLOW HABIT (SECT. 2.2.2)	Ephemeral	(Intermittent)	Perennial but flashy		Perennial
BED MATERIAL (SECT. 2.2.3)	Silt-clay	Silt	Sand	Gravel	Cobble or boulder
VALLEY; OR OTHER SETTING (SECT. 2.2.4)	Low relief valley (<100 ft. or 30 m deep)	Moderate relief (100-1000 ft. or 30-300 m)	 High relief (>1000 ft. or 300 m)	No valley; alluvial fan	
FLOOD PLAIN (SECT. 2.2.5)	 Little or none (<2X channel width)	 Narrow (2-10 channel width)	Wide (>10X channel width)		
NATURAL LEVEES (SECT. 2.2.6)	Little or None	Mainly on Concave	Well Developed on Both Banks		
APPARENT INCISION (SECT. 2.2.7)	Not Incised	 Probably Incised			
CHANNEL BOUNDARIES (SECT.. 2.2.8)	 Alluvial	Semi-alluvial	Non-alluvial		
TREE COVER ON BANKS (SECT. 2.2.8)	<50 percent of bankline		50-90 percent		>90 percent
DEGREE OF SINUOSITY (SECT. 2.2.9)	Straight Sinuosity 1-1.05)	Sinuous (1.06-1.25)	 Meandering (1.25-2.0)	Highly meandering (>2)	
DEGREE OF BRAIDING (SECT. 2.2.10)	Not braided (<5 percent)	Locally braided (5-35 percent)	Generally braided (>35 percent)		
DEGREE OF ANABRANCHING (SECT. 2.2.11)	Not anabranched (<5 percent)	Locally anabranched (5-35 percent)	Generally anabranched (>35 percent)		
VARIABILITY OF WIDTH AND DEVELOPMENT OF BARS (SECT. 2.2.12)	Equiwidth	Wider at bends	 Random variation		
	Narrow point bars	Wide point bars	Irregular point and lateral bars		

Geomorphic factors that affect stream stability.

III. LANE RELATIONSHIP AND OTHER GEOMORPHIC CONCEPTS

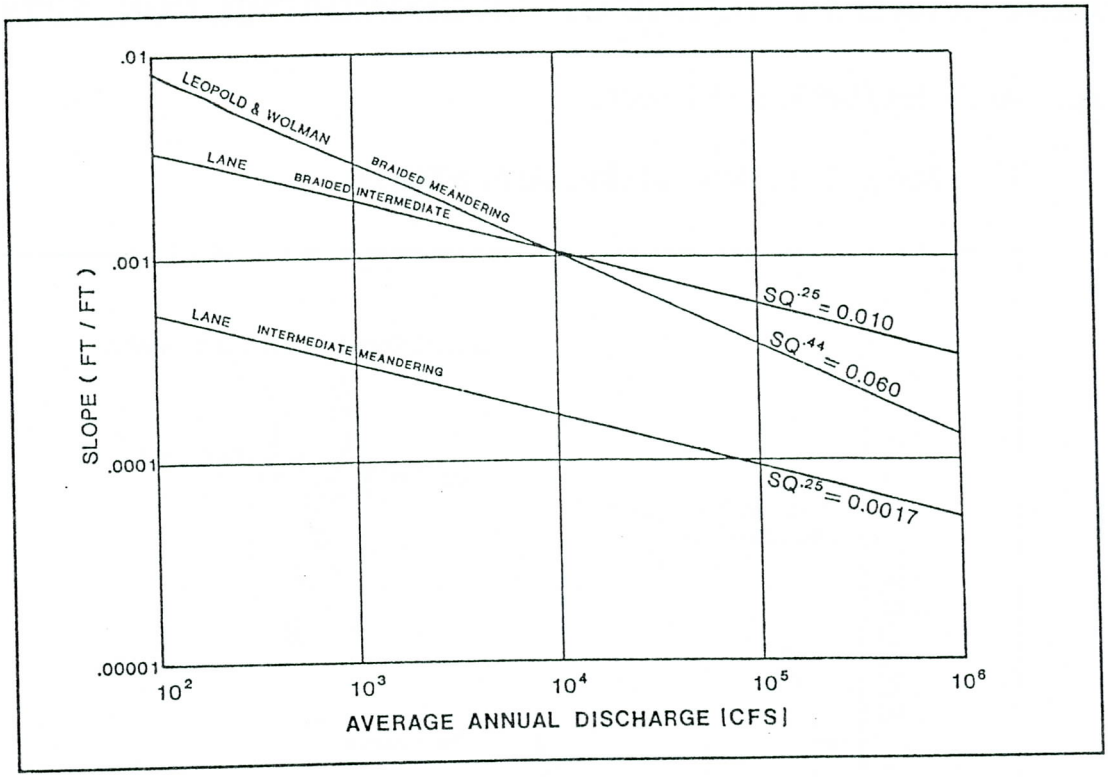
A. Analyzing Plan Form Response

1. Stream form-slope relationship (see Figure)



Sinuosity vs. slope with constant discharge.

2. Slope-discharge relationship (see Figure)



Slope-discharge relationship for braiding or meandering in sand bed streams.

3. Lane Relation

$$\boxed{QS \propto Q_s D_{50}}$$

IV. STREAM CHANNEL GRADATION

A. Sediment Continuity Concept

1. Distinction between sediment transport capacity and sediment supply.

2. Transport capacity generally proportional to velocity to the 3-5 power.

LESSON 3

STREAM STABILITY - HYDRAULIC FACTORS AND PRINCIPLES

I. HYDRAULIC FACTORS AFFECTING STREAM STABILITY

A. The following figure summarizes hydraulic factors affecting stream stability. Each factor is summarized below.

1. Design Flow

   a. The term "design flood" should be avoided, because bridge crossings cannot typically be designed for a unique flood event.

   b. In reality, a range of events should be examined to determine which design condition is most advantageous, insofar as costs and risks are concerned.

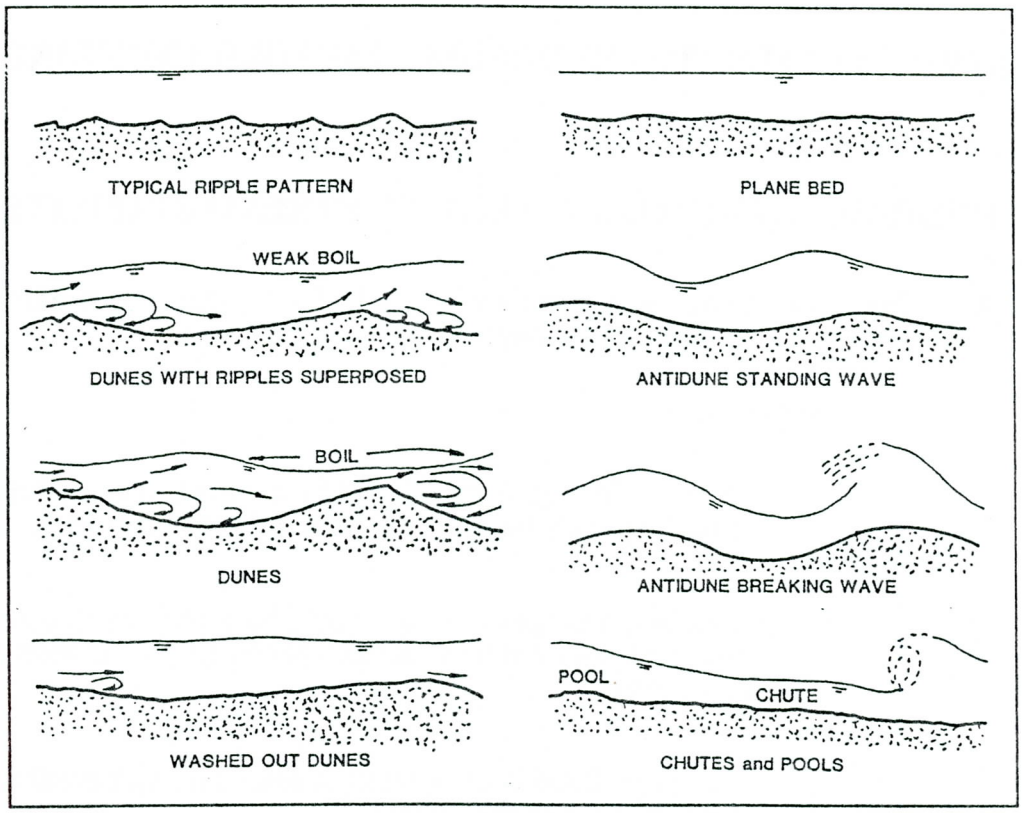
   c. If a design flood is designated, it should be that event that causes the greatest stress to the crossing.

2. Bed Configurations in Sand Bed Streams

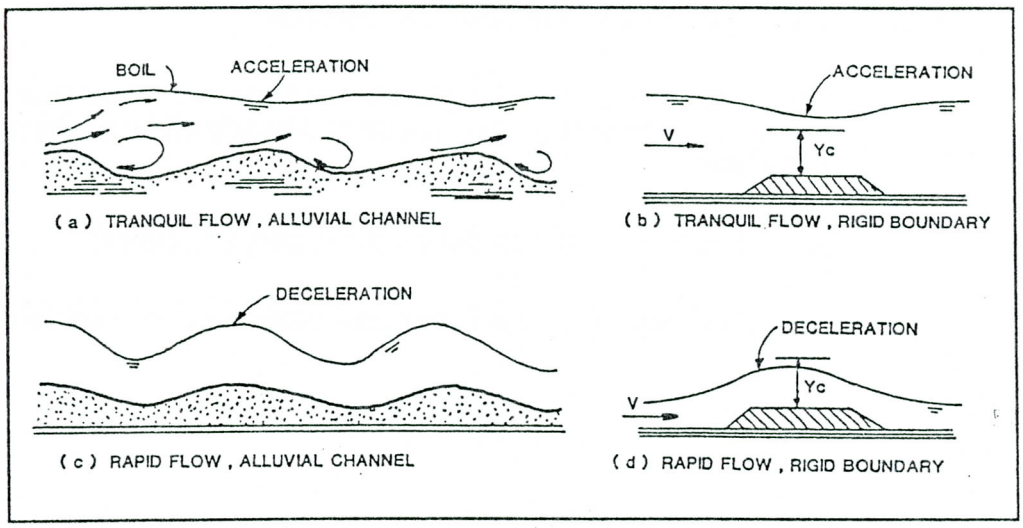
   Sand bed streams are important because most streams flow on sandbeds for the greater part of their length and nearly all large rivers have sandbeds.

   a. Bedforms (ripples, dunes, plane bed, antidunes).

      Bedform condition influences water surface condition.



Forms of bed roughness in sand channels.



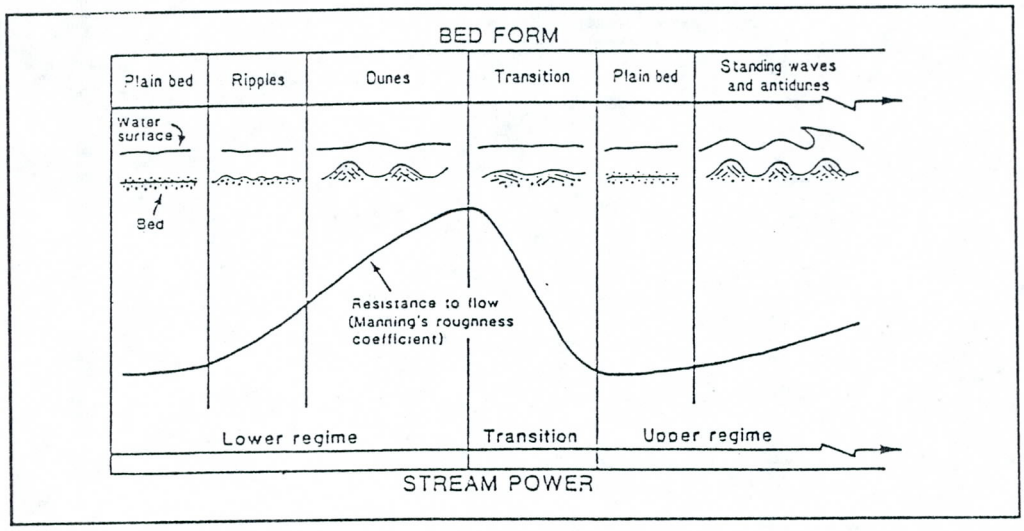
Relation between water surface and bed configuration.

See HEC-20, Section 3.2.3 for further information on the use of this equation, and its application to floodplains.

Reference: USGS Professional Paper 2339, 1989, "Guide for Selecting Roughness Coefficients for Natural Channels and Flood Plains."

b. Sand Bed Channels

Manning n changes with bed configuration.

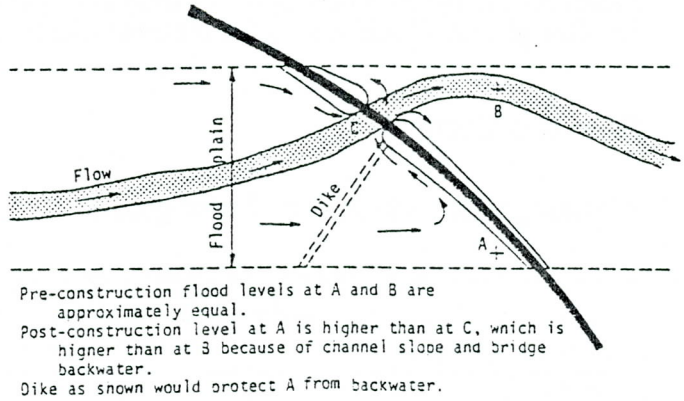


Relative resistance to flow in sand bed channels.

Values range from as high as 0.04 at low flow to as small as 0.012 at high flow. (See Table below).

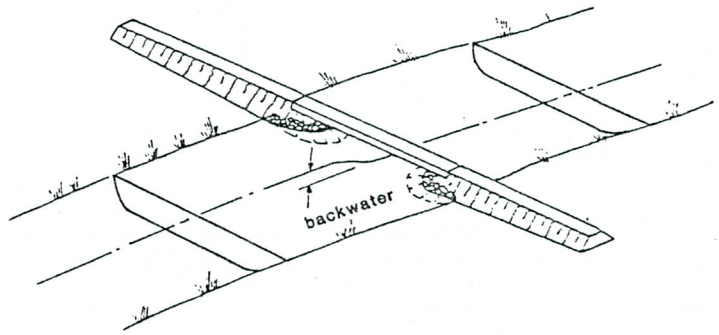
Subcritical flow (Fr < 1.0)	
plane bed	0.014 - 0.020
ripples	0.018 - 0.030
dunes	0.020 - 0.040
washed out dunes or transition	0.014 - 0.025
plane bed	0.010 - 0.013
Supercritical flow (Fr > 1.0)	0.010 - 0.015
standing waves	0.012 - 0.020
antidunes	0.012 - 0.020

Manning roughness coefficients for alluvial sand bed channels. (No vegetation, data limited to sand channels with d_{50} < 1.0 mm).

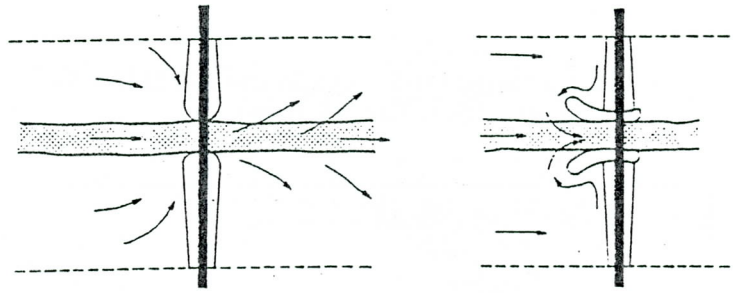


Pre-construction flood levels at A and B are approximately equal.
Post-construction level at A is higher than at C, which is higher than at B because of channel slope and bridge backwater.
Dike as shown would protect A from backwater.

(a) A skewed alignment across a floodplain



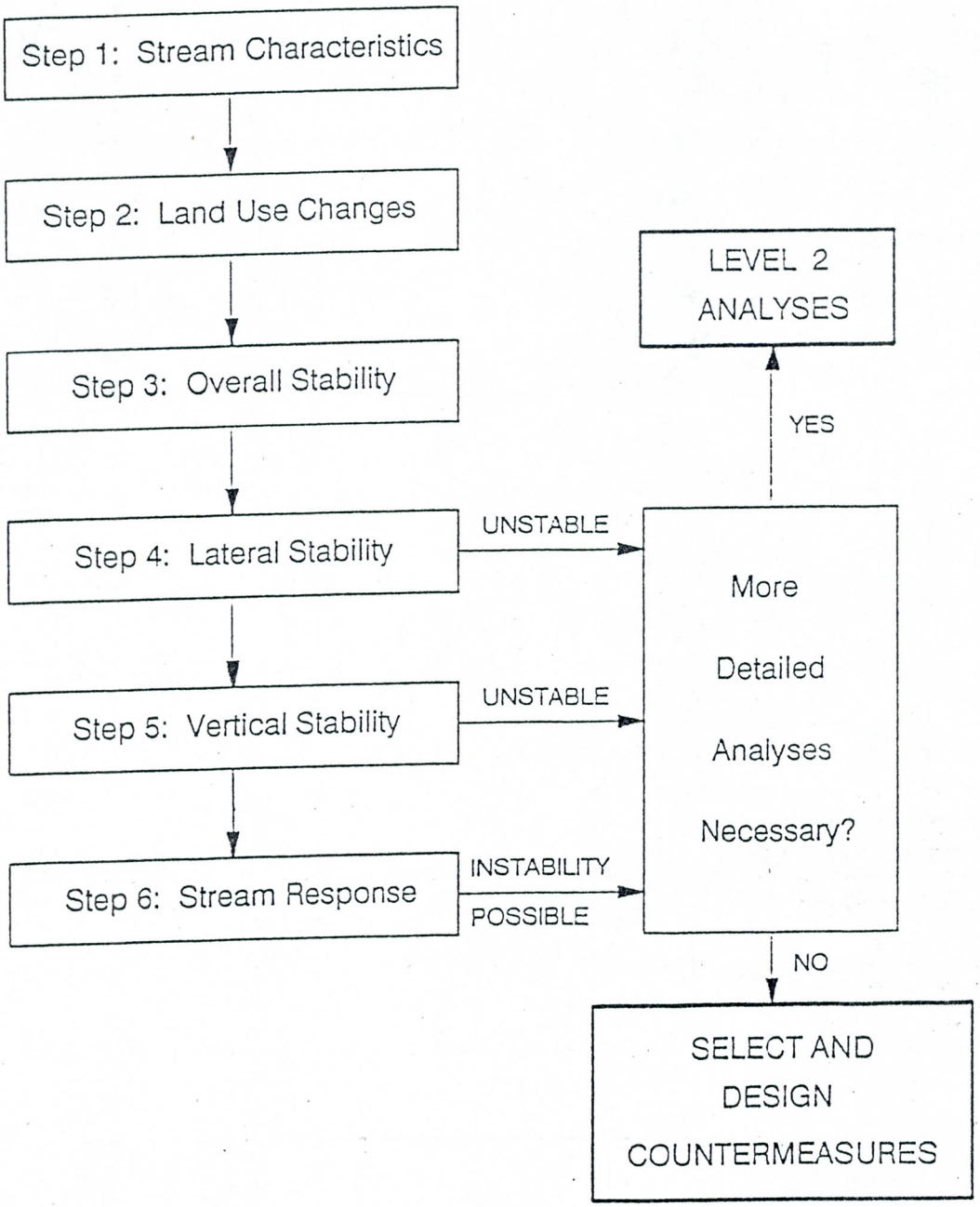
(b) Constriction of channel flow



(c) Constriction of overbank flow

Backwater effect associated with three types of stream crossings: (a) a skewed alignment across a floodplain, (b) constriction of channel flow, and (c) constriction of overbank flow.

LEVEL 1: QUALITATIVE ANALYSES

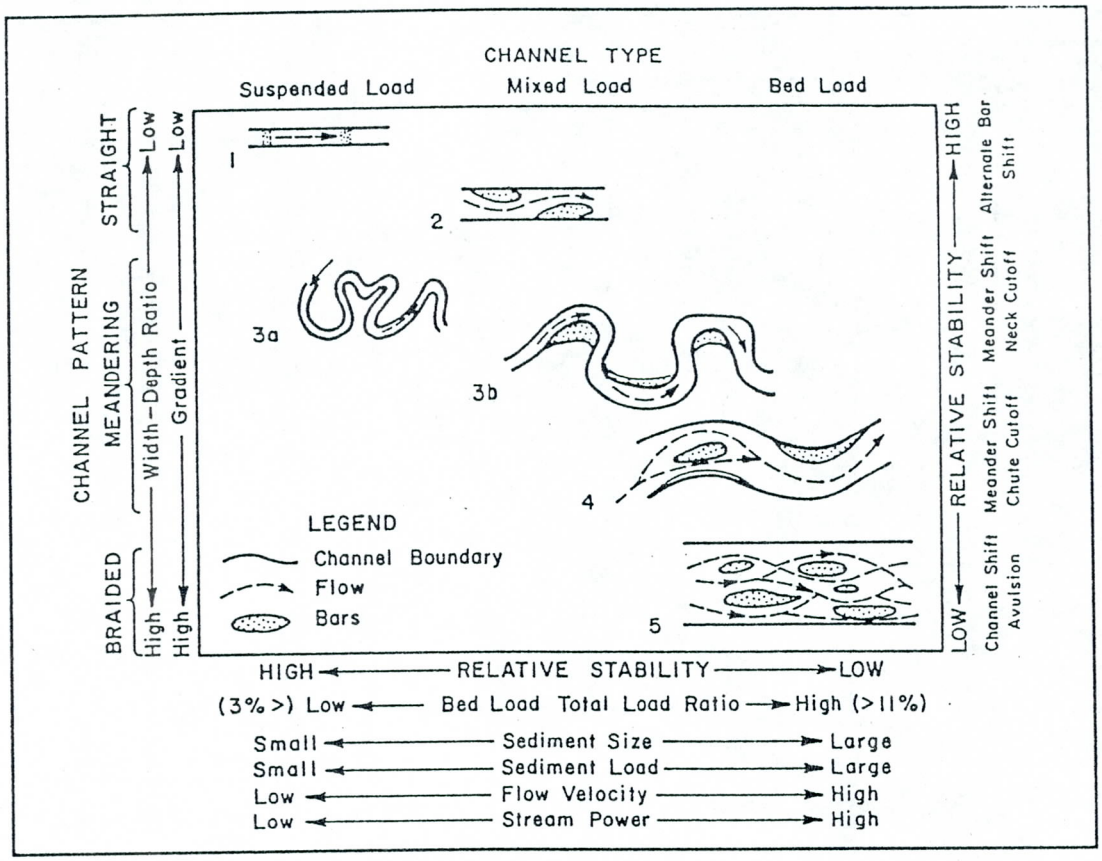


LEVEL 1 FLOW CHART

INTERPRETATION OF OBSERVED DATA

OBSERVED CONDITION	CHANNEL RESPONSE			
	STABLE	UNSTABLE	DEGRADING	AGGRADING
Alluvial Fan				
Upstream on Fan		X		X
Downstream on Fan		X	X	
Dam and Reservoir				
Upstream of Dam		X		X
Downstream of Dam		X	X	
River Form				
Meandering	X	X	Unknown	Unknown
Straight		X	Unknown	Unknown
Braided		X	Unknown	Unknown
Bank Erosion		X	Unknown	Unknown
Vegetated Banks	X		Unknown	Unknown
Head Cuts		X	X	
Diversion				
Clear water diversion		X	↑	X
Overloaded w/sediment		X	X	↓
Channel Straightened		X	X	
Deforest Watershed		X		X
Drought Period	X			X
Wet Period		X	X	
Bed Material Size				
Increase		X		X
Decrease		X	Unknown	X

3. Similarly, the following figure may be useful in making a qualitative assessment of stream stability. For example, it indicates that straight channels are stable only where velocity and sediment load are low.



EVALUATION OF RELATIVE STABILITY

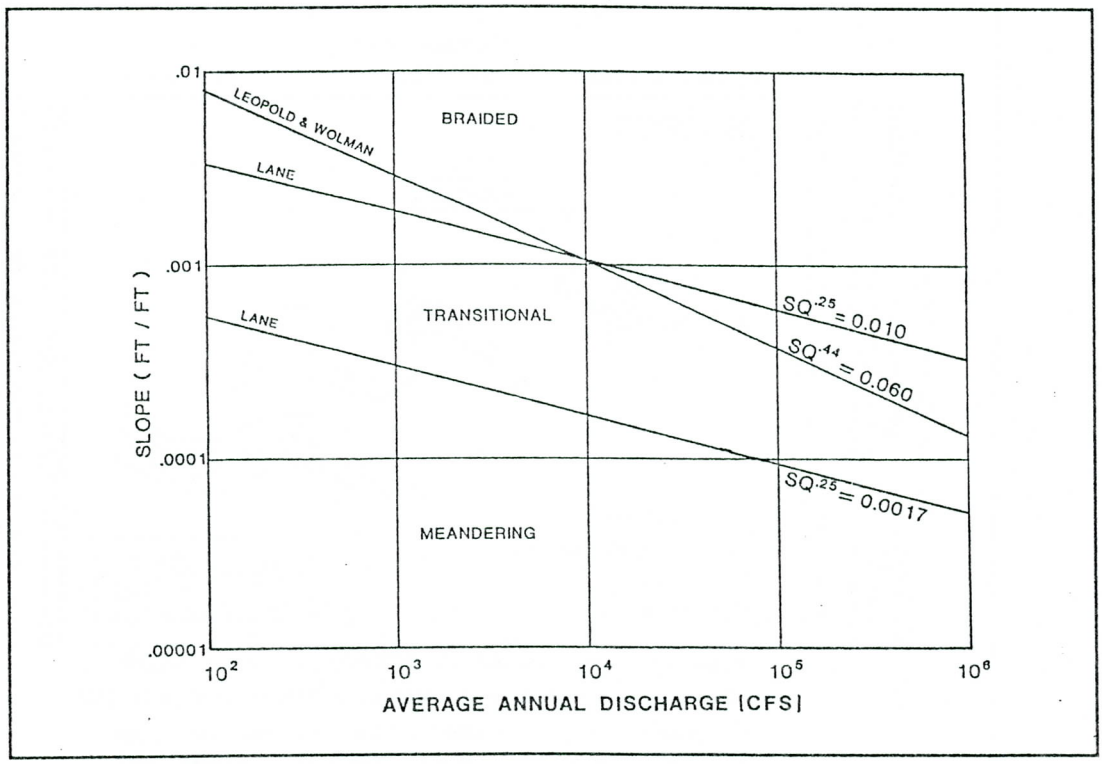
E. Step 4. Evaluate lateral stability.

1. Bank erosion at a bridge site can undermine piers and abutments or breach approach fills. Migration of a bend through a bridge opening will change the direction of flow and possibly aggravate local scour.

2. Field inspection is a critical component of a qualitative assessment of lateral stability.

3. Active bank erosion can be recognized by falling or fallen vegetation, cracks along the bank surface, slump blocks, live vegetation in the flow, increased turbidity, fresh vertical faces, newly formed bars, etc.

2. The slope discharge relation (see Figure) may be useful in predicting channel response to a change in slope, for example from channel straightening, or a change in mean annual discharge as might result from diversion of flow.



Slope-discharge relationship for braiding or meandering in sand bed streams.

3. The Lane relation is useful to qualitatively predict long term channel response to changes in water or sediment discharge, channel slope or medium particle size.

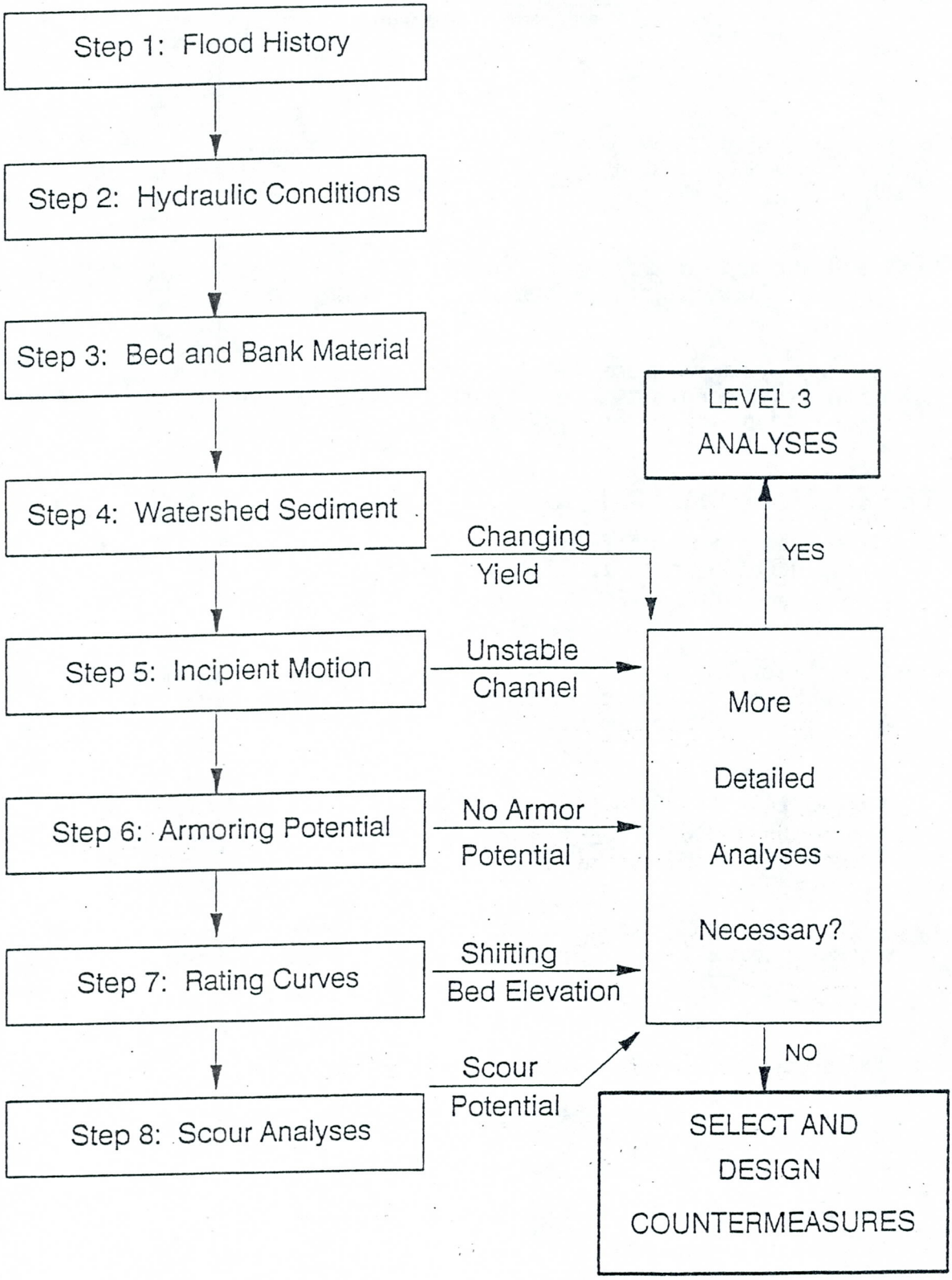
$$QS \sim Q_s D_{50}$$

III. CONCLUSIONS

A. Level 1 analysis results in a qualitative assessment of stream stability.

B. If stream instability exists, a decision is made to either proceed to the more detailed Level 2 evaluation, or to select and design countermeasures based only on the Level 1 assessment.

LEVEL 2: BASIC ENGINEERING ANALYSES



LEVEL 2 FLOW CHART

B. Incipient motion defined by:

$$D_c = \frac{\tau}{0.047(\gamma_s - \gamma)}$$

C. Shields parameter is not constant. A value of 0.047 provides good results in sand channels, while a value of 0.030 may be more reasonable in cobble channels.

D. Incipient motion analysis typically completed for a range of discharges to define what particles are at incipient motion for a given discharge.

E. Results typically more useful for gravel or cobble-bed channels, since application of incipient motion to a sand bed stream typically indicates that all particles are in motion for even very small discharges.

VII. STEP 6: EVALUATE ARMORING POTENTIAL

A. Development of an armor layer (coarser particles on the surface of the bed) can protect the bed up to the discharge sufficient to disrupt the armor layer itself. Even then, the armor layer can reform as flows diminish.

B. Potential for development of an armor layer can be assessed using incipient motion analysis and a representative bed-material composition (i.e., typical of depth of the expected degradation).

C. For a given set of hydraulic conditions the incipient motion size is calculated according to Step 5. If no sediment of the computed size or larger is present in the bed, then armoring will not occur.

D. Armoring is probable when the computed incipient motion size is equal to or smaller than the D95 size (the D90 to D95 size is frequently found to be the size paving the channel).

E. The depth of scour necessary to establish the armor layer is:

$$Y_s = y_a\left(\frac{1}{P_c} - 1\right)$$

See page 6-7.

LESSON 6

STREAM STABILITY - EXAMPLES

I. LEVEL I STREAM STABILITY ANALYSIS EXAMPLES

A. The following problem illustrates the application of the Lane relationship, which is a valuable tool for quickly assessing potential stream response to changes in discharge or sediment supply.

The Lane relationships is:

$$QS \alpha Q_s D_{50}$$

1. Effects of a decrease in sediment supply.

The sediment supply available for transport in a stream reach may be reduced by changes in the watershed which reduce erosion (e.g., urbanization), the mining of sand and gravel from the stream, or the construction of a dam upstream of the reach. Based on the Lane relation and assuming no change in water discharge, what impact will these changes in sediment supply have at a downstream bridge crossing?

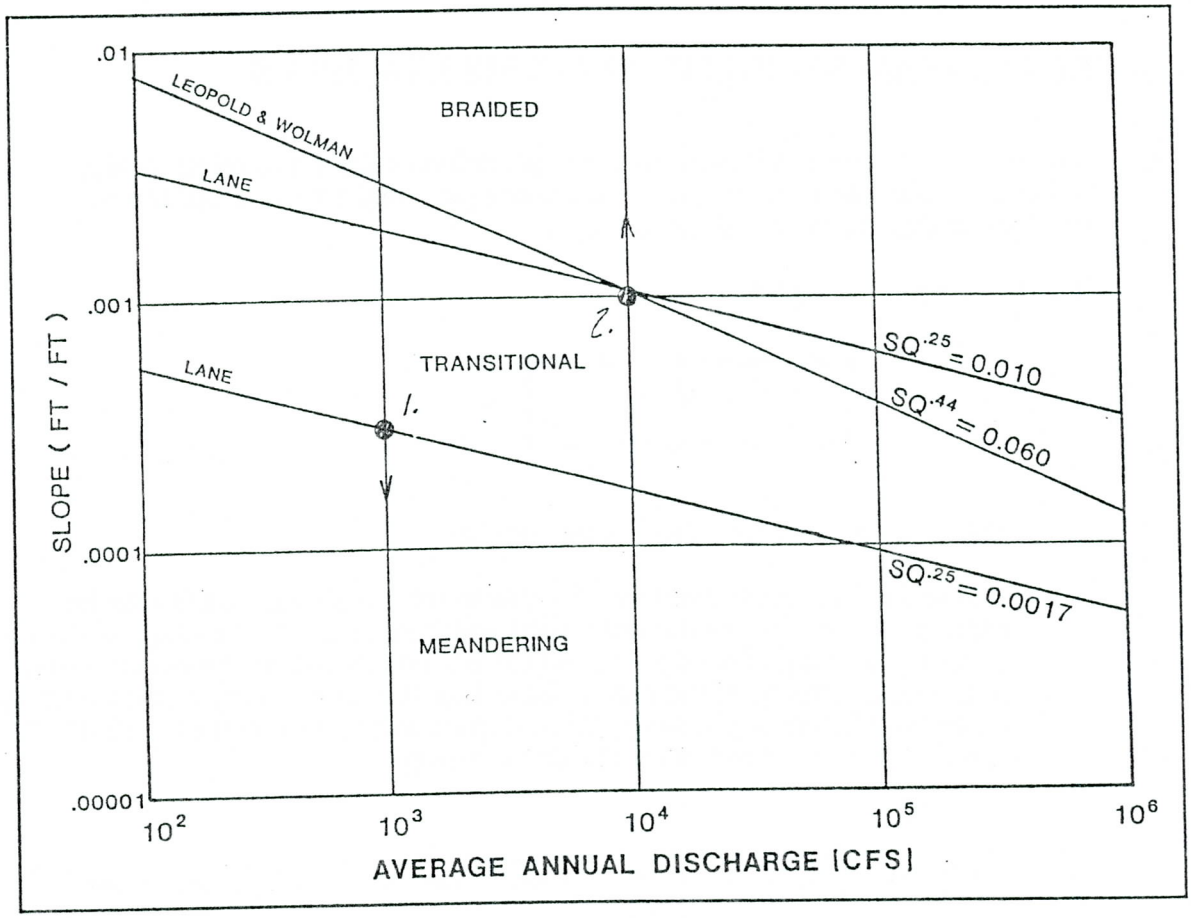
$Q^{o}\underline{\underline{S}}^{-} \alpha Q_s^{-} D_{50}^{o}$ The assumption of Q^{o} is not valid.
Urbanization $\Rightarrow Q^{+}$
New Dam $\Rightarrow Q^{-}$

2. Effects of an increase in sediment supply.

A small tributary upstream of a bridge crossing undergoes a complete burn by fire, resulting in substantial erosion. Based on the Lane relation and assuming no change in water discharge, what impact will this change in sediment supply to the main channel have at the bridge crossing?

$Q^{o}\underline{\underline{S}}^{+} \alpha Q_s^{+} D_{50}^{o}$ The burning of the watershed would change runoff, $Q \neq Q^{o}$.

B. The following problems illustrate the application of the slope-discharge relation, which is useful for evaluating potential changes in planform, specifically, changes from meandering to braided and vice-versa. For example, if a river is meandering, but its slope and discharge borders on the transitional zone a relatively small increase in channel slope may cause it to change, with time, to a transitional or braided river.



SLOPE-DISCHARGE RELATIONSHIP FOR BRAIDING OR MEANDERING IN SAND BED STREAMS

1. For problem I.A.1 above, assume that the average annual discharge was 1000 cfs and the channel slope prior to the reduction in sediment supply was 0.0005. What potential change may occur in stream planform given the reduction in sediment supply and corresponding channel slope adjustment, and what are the potential impacts on the bridge?

$Q_o S^- \propto Q_s^- D_{50}^0$ ∴ reach will tend to meander. Potential degradation.

(Note: From paragraph B above, initial S, Q relation borders the transitional zone.)

2. For problem I.A.2 above, assume that the average annual discharge was 10,000 cfs and the channel slope prior to the burn in the tributary watershed was 0.001. What potential change may occur in the main stream planform given the increase in tributary sediment and the corresponding channel slope adjustment, and what are the potential impacts on the bridge?

$Q^{0} S^{+} \propto Q_s^{+} D_{50}^{0}$ ∴ reach will tend to braid (due to additional sediment supply.)

Potential aggradation.

II. LEVEL II STREAM STABILITY ANALYSIS EXAMPLES

A. The following example illustrates an incipient motion calculation.

1. A scour vulnerability assessment is being completed for a bridge on a river with well-graded bed material ranging from fine sand to coarse gravel and cobbles. A critical issue for the assessment is whether predicted contraction scour will be limited by development of an armor layer on the stream bed. Incipient motion analysis can contribute to resolving this issue.

2. Based on the average of two large samples, one taken upstream and the other downstream of the bridge, a representative particle size gradation curve was developed. The resulting d50 of the bed material was found to be about 4 inches (small cobbles).

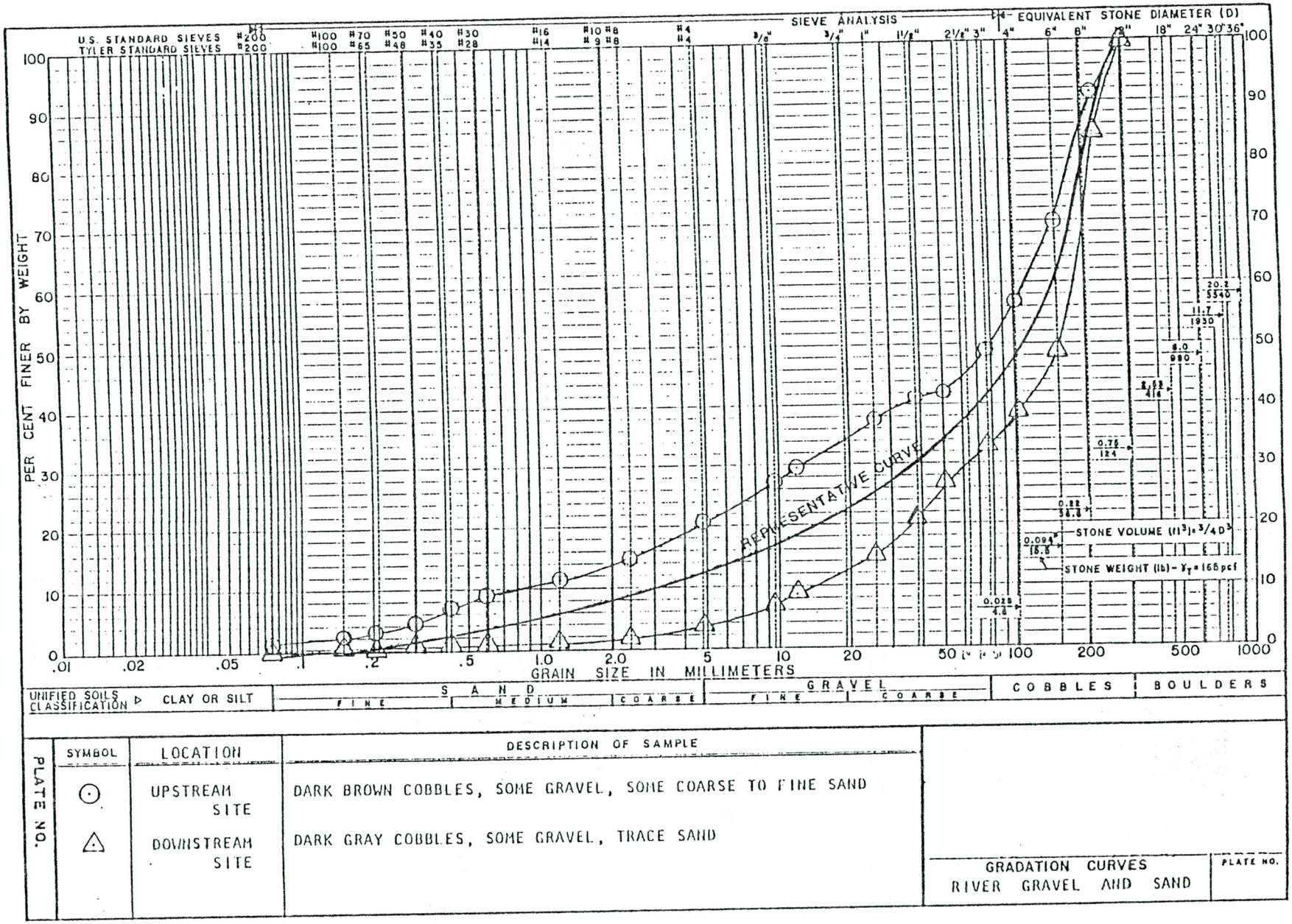


PLATE NO.	SYMBOL	LOCATION	DESCRIPTION OF SAMPLE
	⊙	UPSTREAM SITE	DARK BROWN COBBLES, SOME GRAVEL, SOME COARSE TO FINE SAND
	△	DOWNSTREAM SITE	DARK GRAY COBBLES, SOME GRAVEL, TRACE SAND

GRADATION CURVES
RIVER GRAVEL AND SAND

PLATE NO.

PARTICLE SIZE GRADATION CURVE

3. The hydraulic forces acting in the bridge reach, specifically the tractive force or boundary shear stress, can be evaluated based on hydraulic results from WSPRO analysis. The calculations were completed at 10,000 cfs increments throughout the design hydrograph and resulted in the following average channel velocity and flow depth.

Discharge (cfs)	Velocity (fps)	Flow Depth (ft)
10000	3.7	9.6
20000	5.5	12.4
30000	7.0	14.5
40000	8.3	16.1
50000	9.4	17.5
60000	10.4	18.6
$Q_{100} \rightarrow$ 63100	10.7	19.0

4. The tractive force or boundary shear stress acting on the bed can be computed using the following equation:

$$\tau_o = \frac{\rho V^2}{[5.75 \log\left(12.27 \frac{y_o}{k_s}\right)]^2}$$

where the grain roughness K_s was taken as the d90 size (about 0.7 ft.).

Knowing the boundary shear stress acting on the channel bed at various discharges, the Shields relation can be used to calculate the corresponding incipient motion sizes.

$$D_c = \frac{\tau}{0.047(\gamma_s - \gamma)}$$

$\gamma_s - \gamma$ is the submerged weight of particle, $= (2.65-1)\gamma = 103.0$ pcf

For purposes of illustration, the calculations will also be completed with a Shields parameter of 0.03 (instead of 0.047) which, based on recent research, is more appropriate for cobble bed conditions.

$$\tau_o = \frac{1.94 \text{ slugs/ft}^3 \cdot V^2 \text{ ft}^2/\text{s}^2}{\left[5.75 \log\left(12.27 \frac{y_o \text{ ft}}{K_s \text{ ft}}\right)\right]^2} = \frac{1.94(7.0)^2}{\left[5.75 \log\left(12.27 \frac{14.5}{0.7}\right)\right]^2} = 0.497 \text{ psf}$$

6-5 and $= \frac{1.94(9.4)^2}{\left[5.75 \log\left(12.27 \frac{17.5}{0.7}\right)\right]^2} = 0.838$ psf

$$D_c = \frac{\tau \text{ lb/ft}^2}{0.047 \text{ or } 0.030 \quad 103 \text{ lb/ft}^3}$$

τ	0.497	0.838
0.047	0.103	0.173
0.030	0.161	0.271

$\times 12$ in/ft

Discharge	Velocity	Flow Depth	Shear Stress	Incipient Motion Size	
				0.047	0.030
(cfs)	(fps)	(ft)	(psf)	(in)	(in)
10000	3.7	9.6	.162	.4	0.6
20000	5.5	12.4	.325	.8	1.3
30000	7.0	14.5	.497	1.2	1.9
40000	8.3	16.1	.673	1.7	2.6
50000	9.4	17.5	.838	2.1	3.3
60000	10.4	18.6	1.005	2.5	3.9
63100	10.7	19.0	1.056	2.6	4.1

The results indicate that during the design flood, hydraulic forces adequate to transport bed material up to sizes as large as 2.6-4.1 inches, corresponding to the d39-d48 size range would be generated by the flow. Assuming that the results based on a Shields parameter of 0.030 are more correct (4.1 inches, equal to d48 size), 48 percent of the bed material is composed of sizes that could be transported by the hydraulic forces generated during peak flow conditions. Note that this does not imply that 48 percent of the bed material would be in motion during the peak flow of the flood; only that the hydraulic forces necessary to transport particles in 48 percent of the bed material were available. The actual quantity transported is a function of many other factors, including armoring and upstream sediment supply.

B. The following example illustrates the analysis of armoring potential.

1. The armoring process begins as the non-moving coarser particles segregate from the finer material in transport. Potential for development of an armor layer can be assessed using incipient motion analysis and a representative bed-material composition. The representative bed-material composition should be typical of the depth of anticipated degradation. If no sediment of the computed size or larger is present in the significant quantities in the bed, armoring will not occur.

2. The d90 or d95 size of the representative bed material is frequently found to be the size "paving the channel" when degradation is arrested. Within the practical limits of planning and design, the d95 size is considered to be about the maximum size for pavement formation. Therefore, armoring is probable when the computed incipient motion size is equal to or smaller than the d95 size.

y_s/y_o	Pc	D
19.0	0.05	95
9.0	0.10	90
4.0	0.20	80
1.5	0.40	60
0.67	0.60	40
0.25	0.80	20

LESSON 7

STREAM STABILITY CASE STUDY

I. INTRODUCTION

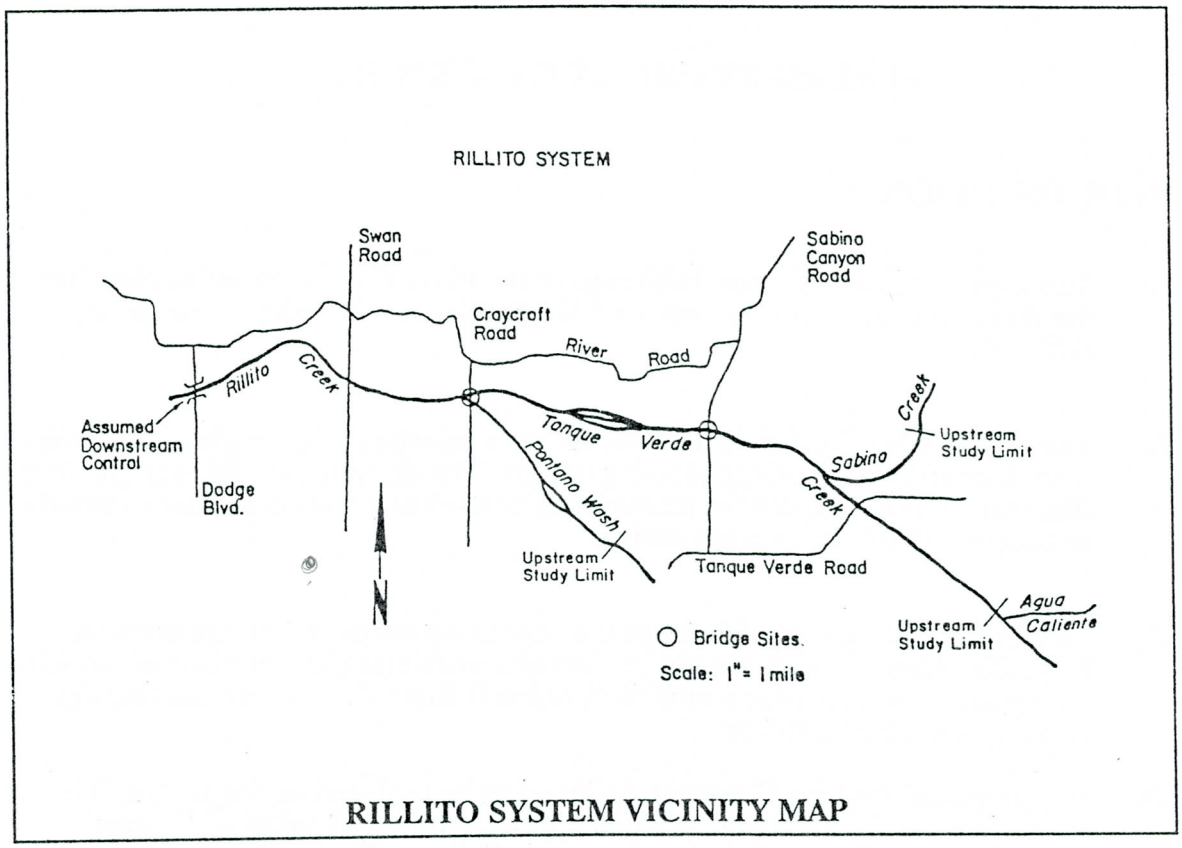
A. This example is taken from "Highways in the River Environment" to illustrate the three level approach to river stability problems. (See also Appendix A, HEC-20.)

B. The Rillito River System in Tucson, Arizona provides an example of the problems encountered in bridge crossing design. **The objective of this example is to illustrate to the designer the methodologies used in a stream stability analysis in support of bridge crossing design.**

C. Two bridge sites are considered in the case study presented in Appendix A, HEC-20. These provide insight into several problems characteristic of the Rillito system. For this lesson only the Craycroft Road site with an existing dip crossing will be considered.

D. It is proposed that the Craycroft dip crossing be replaced with a bridge. The study reach of Rillito River included approximately 11.5 miles of channel extending from Dodge Boulevard to Agua Caliente Wash. This included ~~to~~ two miles on the Rillito River, six and one-half miles upstream of Craycroft Road on the Tanque Verde Creek, two miles upstream of Craycroft Road on Pantano Wash, and one mile on Sabino Creek upstream of the confluence with Tanque Verde Creek.

NOTES:



RILLITO SYSTEM VICINITY MAP

II. LEVEL 1 ANALYSIS

A. Level 1 - Step 1: **Stream characteristics.**

1. Flood events.

Ephemeral Watershed = 9.15 sq. mi. (see page 7-9)
Hydrologic Regime
- general winter storm (1-3 days over most of the watershed) worst event type.
- general summer storms (1-3 days over portions of watershed)
- summer T-storms (short duration - heavy intensity)

2. Geomorphology.

Steep
med. sand to coarse sand bed.
low sinuosity but wants to be braided.

encroached (unnatural condition)

B. Level 1 - Step 2: **Land use changes.**

1. Urban area.

lower reach (construction is to
- less sediment
- increased peak
- encroached

upper reach
- largely in natural condition
- S&G mining

2. Sand and gravel mining.

Apparent by ponded water in aerial photographs

Tonque Verde ~ 190,000 cy/yr removed
Rollito ~ 250,000
Pontana ~ 90,000

3. Undeveloped land.

In natural state

C. Level 1 - Step 3: **Overall stability.**

1. Human activity.

Urbanization
S&G mining
Encroachment

2. Geomorphic changes.

Natural to Encroached and mined.
Wants to be braided but forced to be straight.

D. Level 1 - Step 4: **Lateral stability.**

1. Planform geometry.

$L = 2.6\ r_c$
$L = 2.75\ B^{1.35}$
$r_c = 1.06\ B^{1.35}$

Where:

L = meander wave length
B = channel width
r_c = radius of curvature

Wants to be this way.

E. Level 1 - Step 5: **Vertical stability.**

1. Bridge sites.

Contraction
Pier
Abutment
} Scour

2. Grade control.

Degradation is apparent due to mining, encroachment and steep slope.

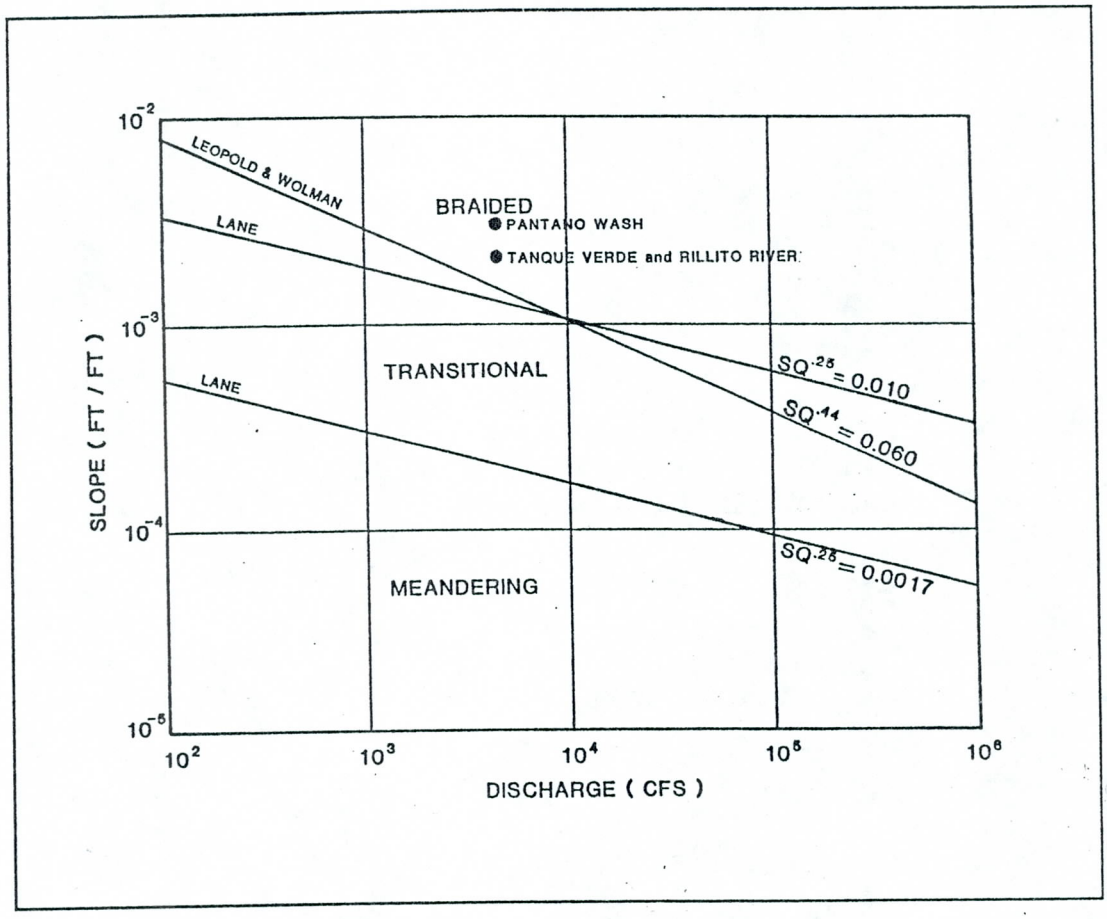
3. Hydraulic control.

At Dodge Road

F. Level 1 - Step 6: **Stream response.**

1. Plan form.

$SQ^{1/4} = .037$ S=0.0024



SLOPE-DISCHARGE RELATIONSHIP FOR RILLITO RIVER

2. General response.

$$Q_s D_{50} \alpha Q S$$

3.Response of gravel pit reach (Swan Road to Dodge Boulevard).

$$Q_s^- D_{50} \alpha Q S^-$$

NOTES:

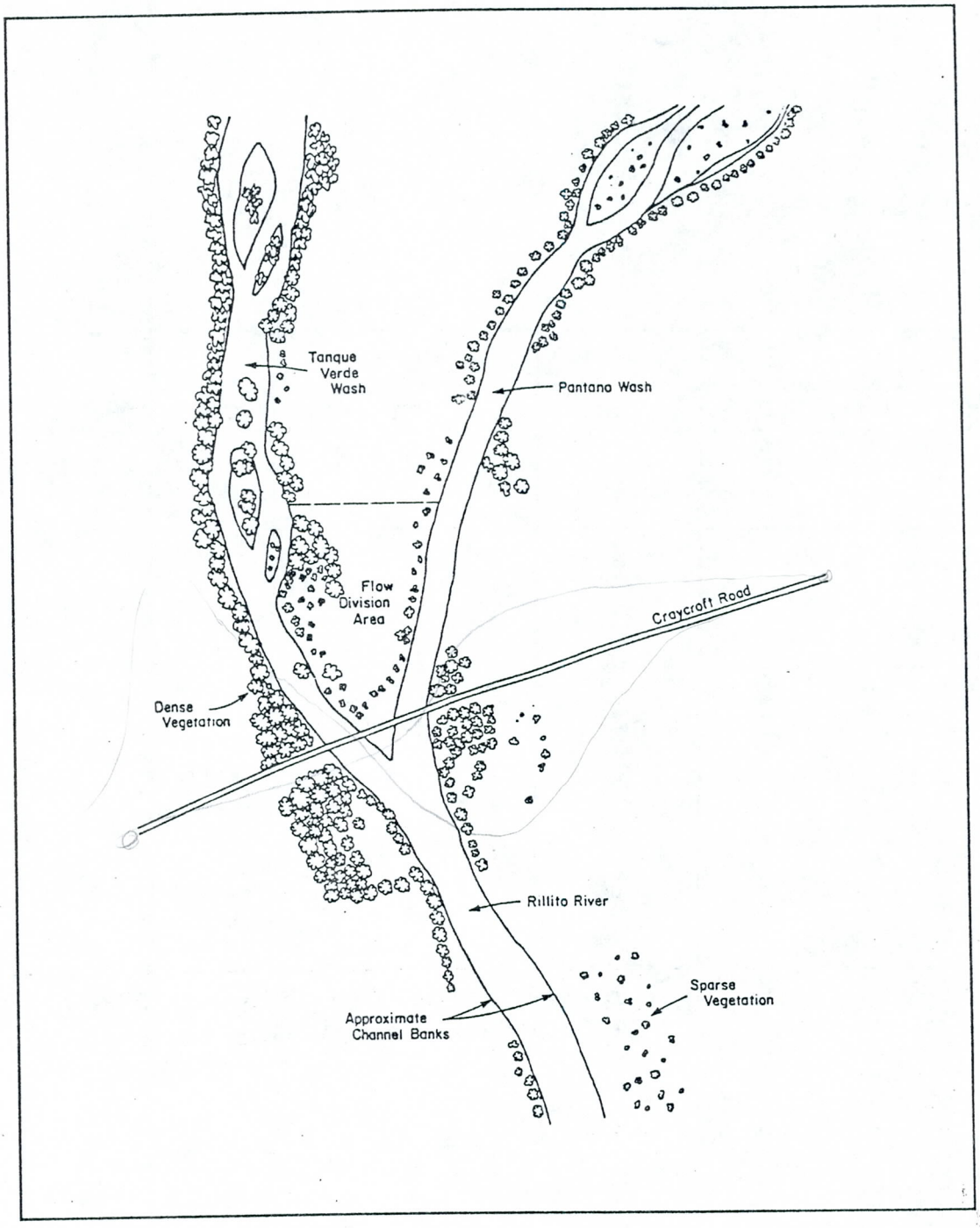
Need to proceed to level 2.

4. Local problems - Craycroft Road.

Proposed bridge to go at confluence of Pontano Wash and Tonque Verde.

The split flow is a problem because one branch can overtop and flow in the other and determining the flow in either branch is difficult.

The bed of Tonque Verde is 3'± higher than Pontano Wash, ∴ overflow can occur.



SKETCH OF CRAYCROFT ROAD BRIDGE CROSSING

a. Hydraulics at confluence.

b. Grade control.

c. Local scour.

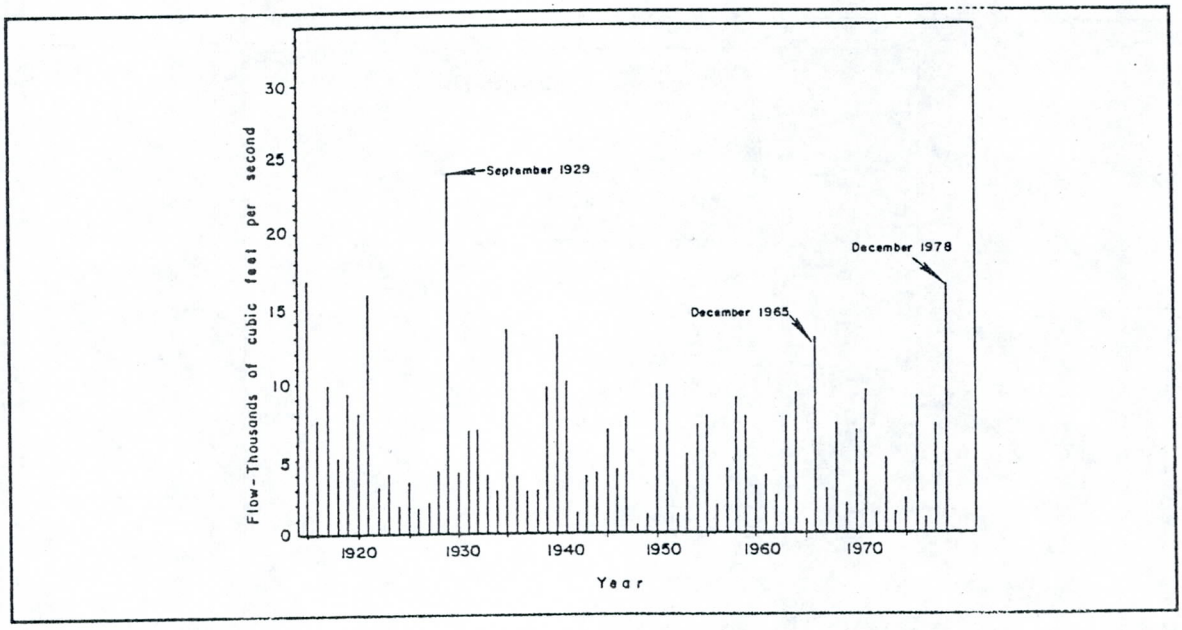
d. Degradation.

III. LEVEL 2 ANALYSIS

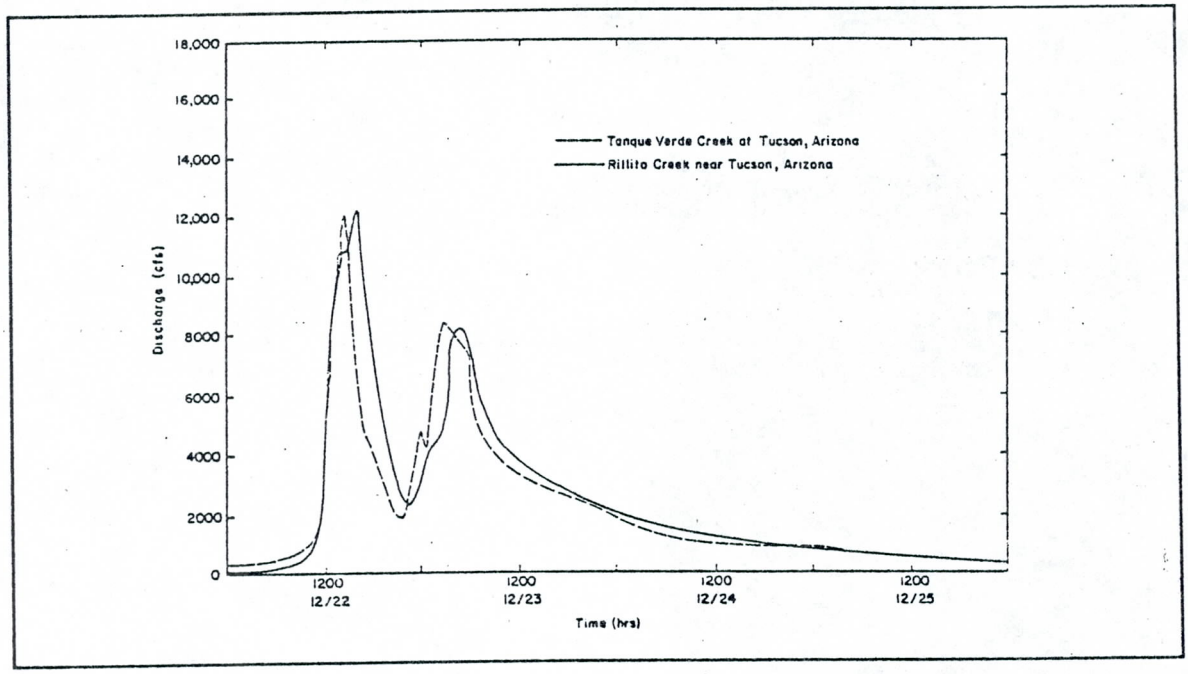
A. Level 2 - Step 1: **Flood History**

Exceedence Probability	Return Period (year)	Expected Discharge (cfs)	95% Confidence Limit	
			Lower (cfs)	Upper (cfs)
0.5000	2	5,000	4,240	5,800
0.2000	5	9,300	7,670	11,100
0.1000	10	12,500	10,100	15,600
0.0400	25	17,200	13,300	22,000
0.0200	50	21,100	15,800	27,300
0.0100	100	25,200	18,400	33,000
0.0050	200	29,800	20,900	39,200
0.0020	500	35,700	24,400	47,800

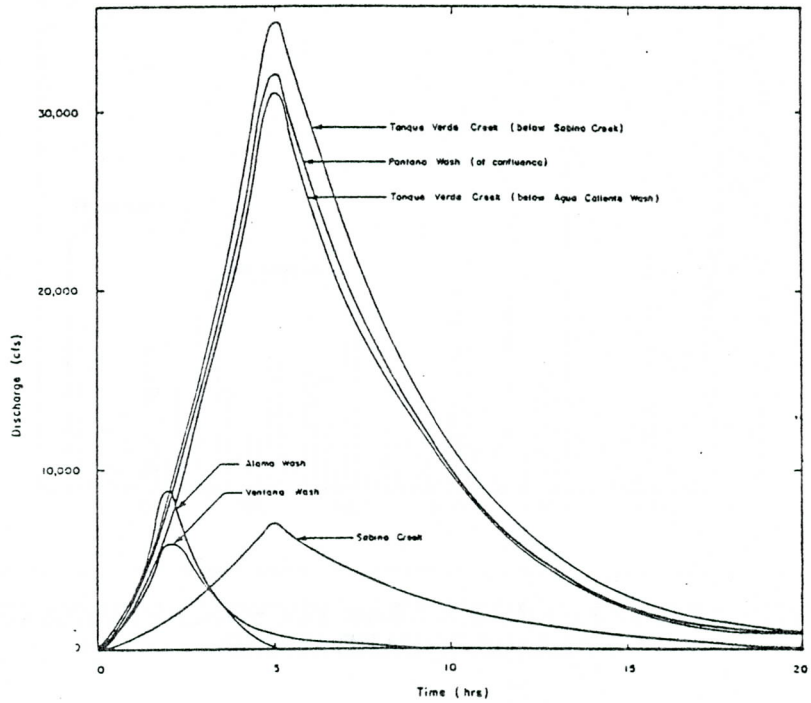
RILLITO RIVER NEAR TUCSON, ARIZONA LOG-PEARSON TYPE III FREQUENCY ANALYSIS BY USGS



FLOOD EVENTS AT RILLITO RIVER NEAR TUCSON, ARIZONA (DRAINAGE AREA 915 SQUARE MILES)



DECEMBER, 1965 FLOOD IN RILLITO RIVER AND TANQUE VERDE CREEK



100-YEAR FLOOD DESIGN HYDROGRAPHS

B. Level 2 - Step 2: **Hydraulic conditions.**

1. Bed forms.

Upper Regime, see page 3-3.

2. Mannings n.

Main channel = 0.025. Also see page 3-5.

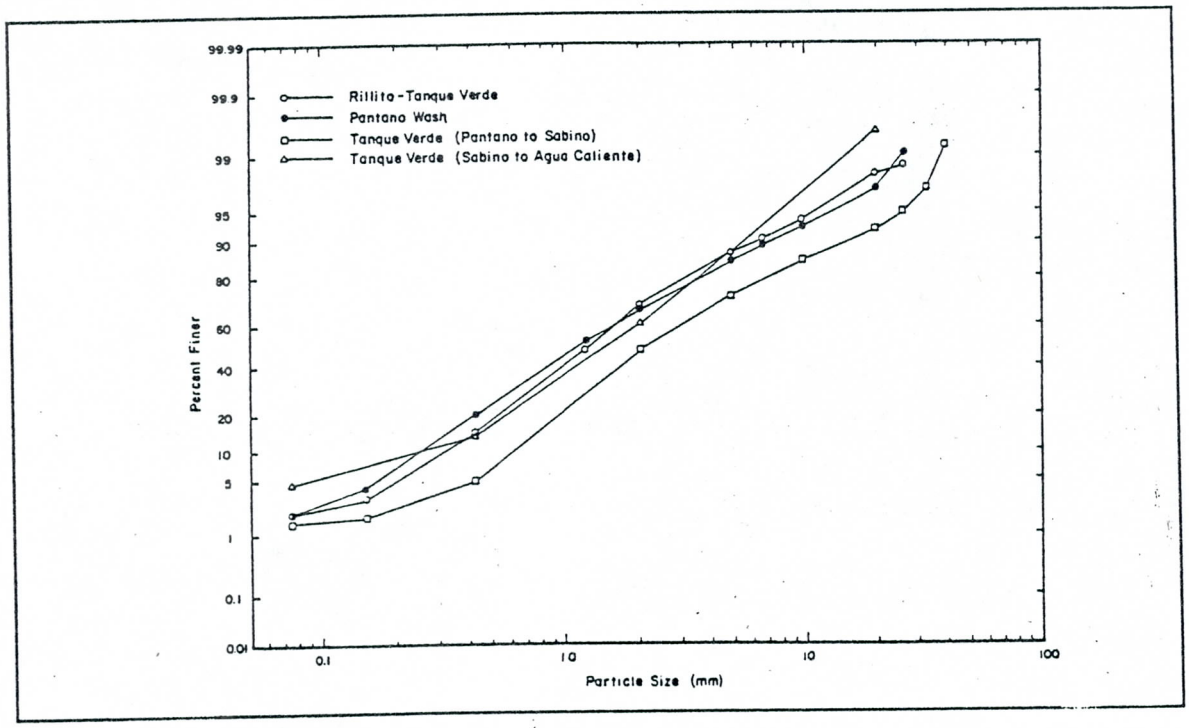
3. Overbank flow.

$n = 0.05$ to 0.06.

4. Water surface profiles.

Conducted from Dodge Road upstream past Craycroft Rd by HEC-2.

C. Level 2 - Step 3: **Bed and bank material.**



RILLITO-PANTANO-TANQUE VERDE BED SEDIMENT DISTRIBUTION

1. Size distribution.

D_{50} = 4mm (coarse sand to fine gravel)

2. Subsurface and bank samples.

Collected from a total of 60 samples. gradation plots for averages of the reaches from the 60 samples are shown on page 7-11.

D. Level 2 - Step 4: **Watershed sediment.**

1. Sediment supply and yield.

↓ Urbanization and ↑ Undeveloped

E. Level 2 - Step 5: **Incipient motion** and Step 6: **Armoring potential.**

1. Coarse material.

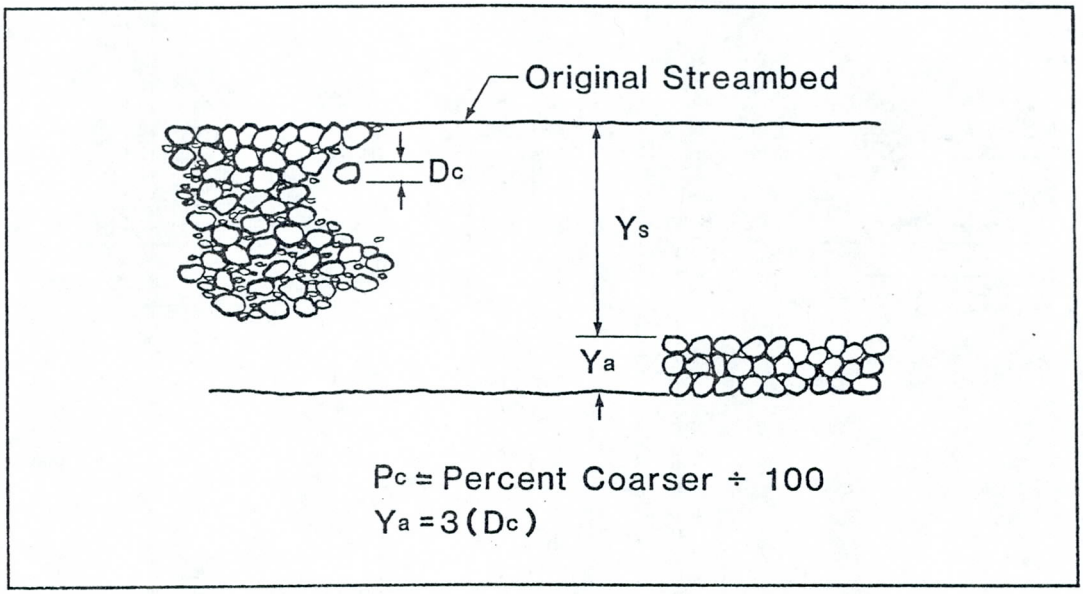
Good armoring potential due to coarse bed.

3. Using the following equation, compute the depth to armoring (Y_s) assuming the incipient size(D_c) is the d_{48} size of the bed material as calculated in Part 4 above.

$$Y_s = Y_a \left(\frac{1}{P_c} - 1\right)$$

$$y_s = 3(4.1\,in)\left[\frac{1}{0.52} - 1\right] = 11.35\,in \approx 1\,ft$$

Note: $D_{50} \approx 4\,in$ Armoring will develop
$D_{48} = 4.1\,in$



4. Thus, it is expected that the bed would armor after 1.0 feet of contraction scour. Note that this conclusion does not preclude bed movement in the immediate vicinity of the bridge due to local effects, such as local scour or riprap movement at the bridge piers.

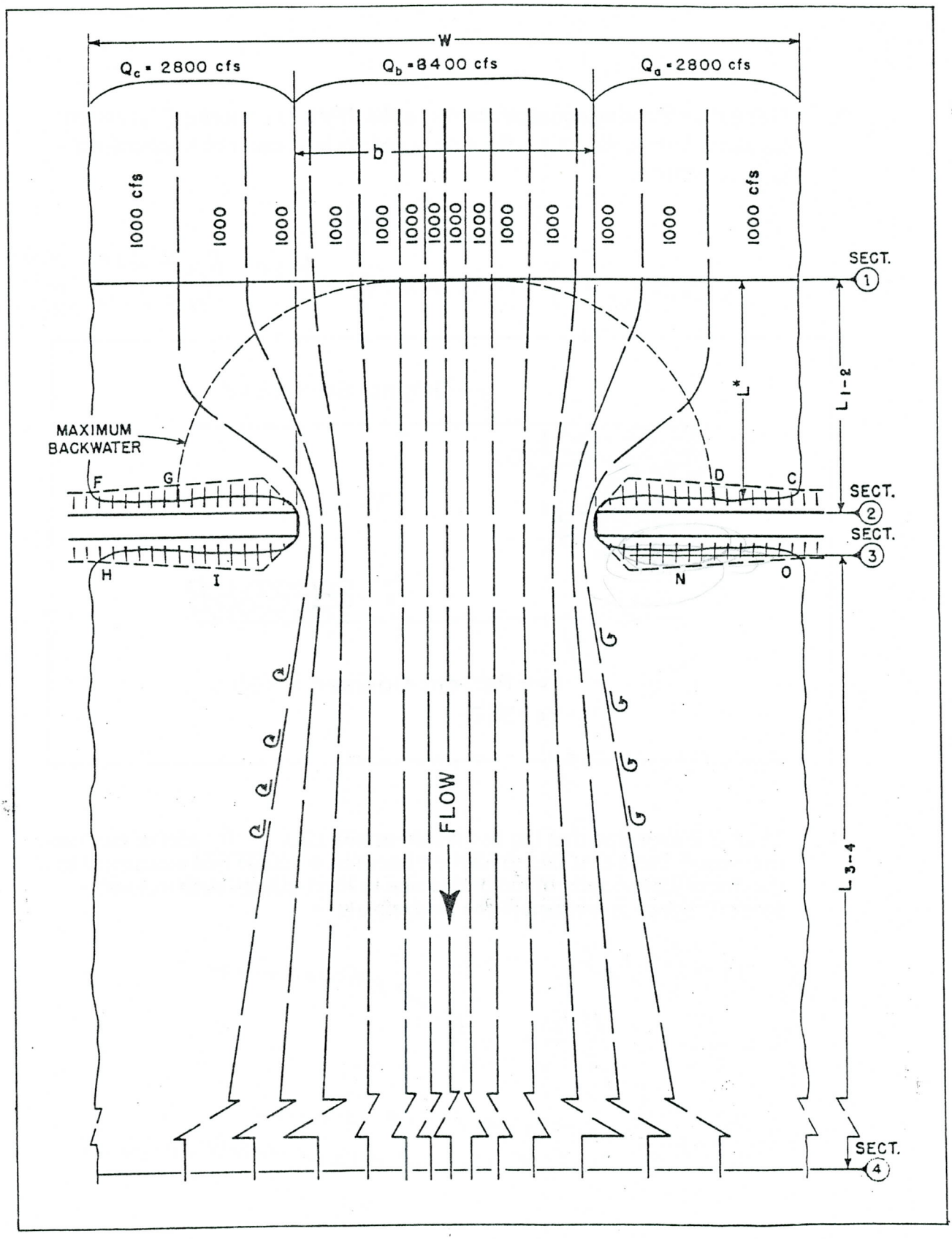
$$y_s = y_a\left(\frac{1}{P_c} - 1\right)$$

percent finer

$$\frac{y_s}{y_a} = \frac{1}{P_c} - 1 = \frac{1 - P_c}{P_c} = \frac{P_f}{P_c}$$

$$\therefore \frac{y_s}{y_a} = \frac{P_f}{P_c}$$

so y_s and P_f are removed while y_a and P_c are left behind.



FLOW LINES FOR TYPICAL NORMAL CROSSING (FHWA, HDS No. 1, 1978)

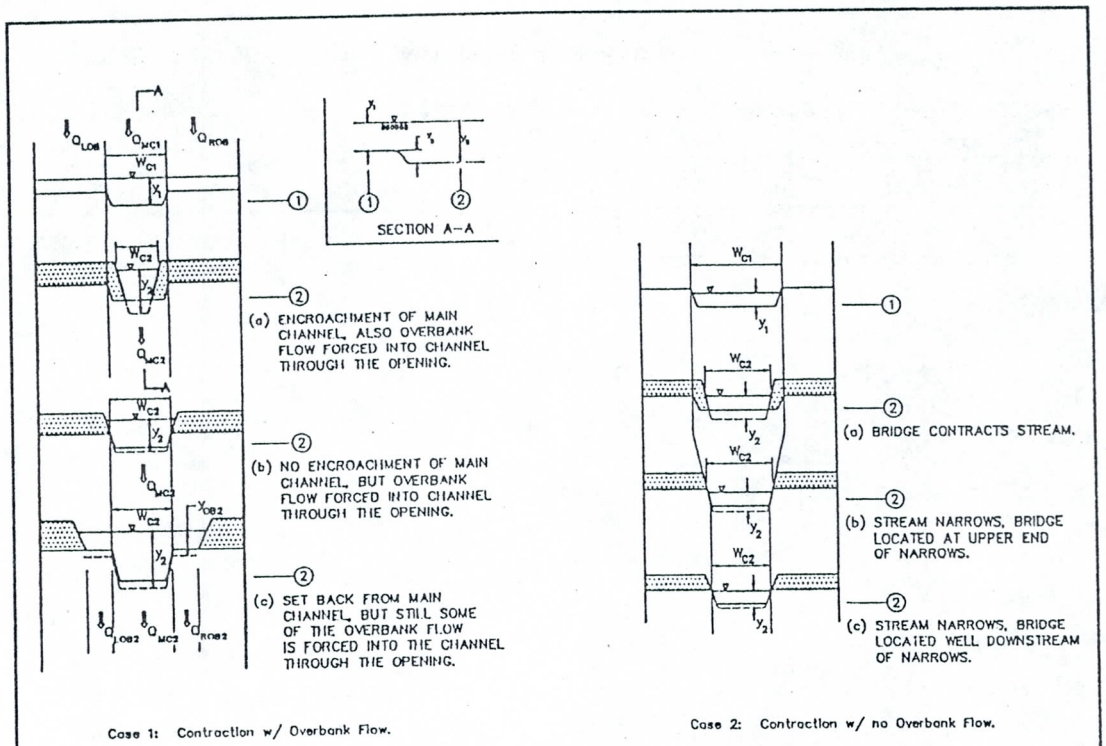


DIAGRAM OF CASE 1 and 2.

B. <u>Case 1.</u> - <u>Streams</u> <u>with</u> <u>Over-bank</u> <u>Flow</u>

Laursen's (1960) live bed contraction scour equation. not to be lower than 1.0

$$\frac{Y_2}{Y_1} = \left(\frac{Q_t}{Q_c}\right)^{6/7} \left(\frac{W_1}{W_2}\right)^{K_1} \left(\frac{n_2}{n_1}\right)^{K_2}$$

$Y_s = Y_2 - Y_1$ Average scour depth

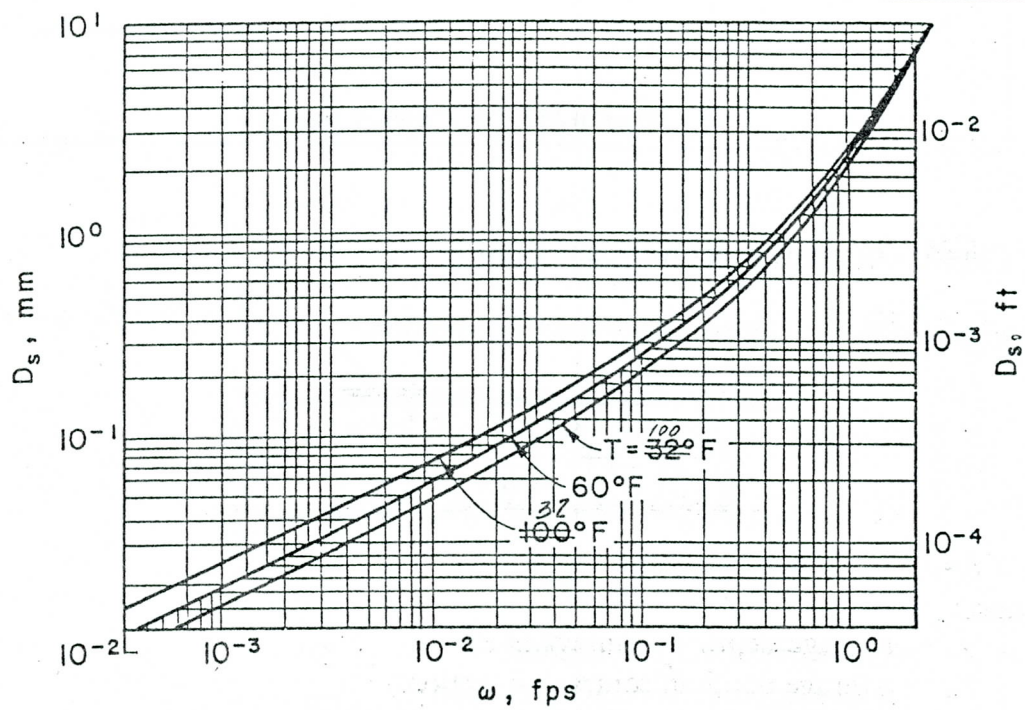
Where:

$Y_1 =$ average depth in main channel
$Y_2 =$ average depth in contracted section
$W_1 =$ bottom width of main channel
$W_2 =$ bottom width of contracted section (with piers subtracted)
$Q_t =$ flow in contracted section
$Q_c =$ flow in main channel
$n_2 =$ Manning n for contracted section
$n_1 =$ Manning n for main channel
$e =$ transport factor from following table

V_{*c}/w	e	K_1	K_2	Mode of Bed Material Transport
<0.5	0.25	0.59	0.066	mostly contact bed material
0.5 to 2.0	1.0	0.64	0.21	some suspended bed material
>2.0	2.25	0.69	0.37	mostly suspended bed material

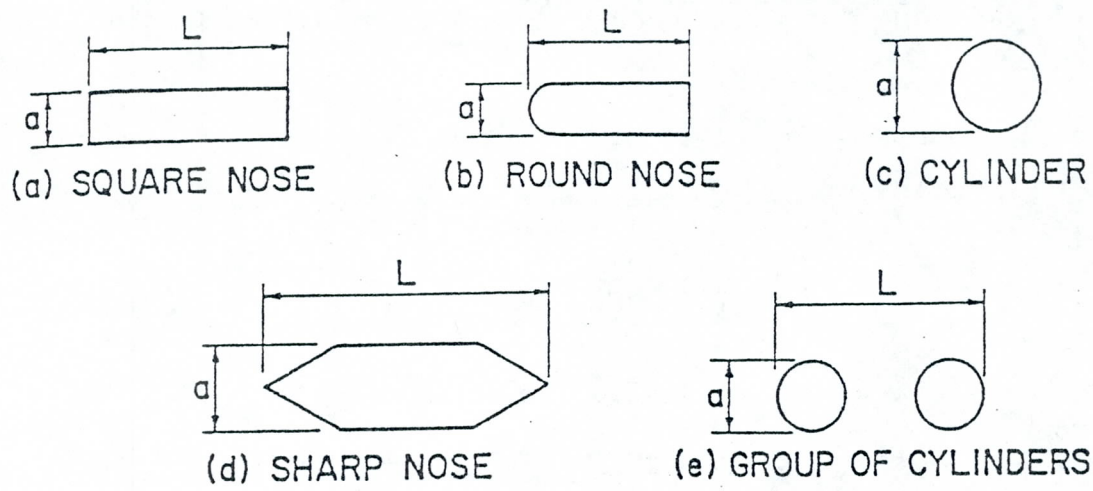
Where:

$V_{*c} = (g y_1 S_1)^{0.5}$, shear velocity
$w =$ fall velocity of D_{50} of bed material (see figure below)
$g =$ gravity constant, 32.2 ft/sec^2
$S_1 =$ slope, energy grade line main channel
$K_1 = \frac{6(2+e)}{7(3+e)}$
$K_2 = \frac{6e}{7(3+e)}$



FALL VELOCITY OF SAND SIZE PARTICLES

Correction Factor, K_1 for Pier Type		Correction Factor, K_2 for Angle of Attack of the Flow			
Type of Pier	K_1	Angle	L/a=4	L/a=8	L/a=12
(a) Square nose	1.1	0	1.0	1.0	1.0
(b) Round nose	1.0	15	1.5	2.0	2.5
(c) Circular cylinder	1.0	30	2.0	2.5	3.5
(d) Sharp nose	0.9	45	2.3	3.3	4.3
(e) Group of cylinders	1.0	90	2.5	3.9	5.0
		Angle = skew angle of flow L = length of pier			



COMMON PIER SHAPES

IV. INFLUENCE OF PIER CAP OR FOOTING ON SCOUR DEPTH.

A. Background.

The extent to which a pier footing or pile can affect local scour at a pier is not clearly determined. Under some circumstances the footing may serve as a scour arrestor, impeding the horseshoe vortex and reducing the depth of scour hole. In other cases where the footing extends above the stream bed into the flow, it may serve to increase the effective width of the pier, thereby increasing the local pier scour.

Recent studies indicate that using pier width in the pier scour equations when the footing is at, below, or slightly above the stream bed elevation gave a more accurate prediction of the observed scour depths (Schoharie Creek bridge failure and laboratory studies at Colorado State University (1987) and by Sterling Jones (1989)).

B. Recommendation.

IT IS RECOMMENDED THAT THE PIER WIDTH BE USED AS THE VALUE OF "a" IN THE PIER SCOUR EQUATIONS IF THE TOP OF THE FOOTING IS SLIGHTLY ABOVE, AT, OR BELOW THE STREAM BED ELEVATION (TAKING INTO ACCOUNT CONTRACTION SCOUR). If the pier footing or pile cap extends above the stream bed, make a second computation using the width of the footing for the value of "a" and the depth and average velocity in the flow zone obstructed by the footing for the "y" and "V", respectively, in the CSU scour equation. Use the larger of the two scour computations.

To determine average velocity in flow zone use:

$$\frac{V_f}{V_1} = \frac{\ln\left(\frac{10.93 y_f}{k_s} + 1\right)}{\ln\left(\frac{10.93 y_1}{k_s} + 1\right)}$$

where:

V_f = average velocity in the flow zone below the top of the footing

y_f = distance from the bed to the top of the footing

k_s = the grain roughness of the bed. Normally taken as the D_{84} of the bed material.

The values of V_f and y_f are used in the CSU equation given above.

V. PIER SCOUR FOR EXPOSED PILE GROUPS

Pile groups that project above the stream bed can be analyzed conservatively by representing them as a single pier width equal to the projected area of the piles ignoring the clear space between piles. Good judgement needs to be used in accounting for debris because pile groups tend to collect debris that could effectively clog the clear spaces between piles and cause the pile group to act as a much larger mass.

C. Recommended Equation

For the determination of pier scour, the Colorado State University's equation is recommended for both live bed and clear water scour.

With a dune bed configuration the equation predicts equilibrium scour depths and maximum scour will be 30% greater.

For flow with plane bed configuration, CSU's equation gives the maximum scour depth.

For antidune flow, CSU's equation gives a scour depth 10%-20% less than maximum scour.

D. Computing Pier Scour (Step 6).

The Colorado State University's equation (Richardson et al, 1975, 1989) is:

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

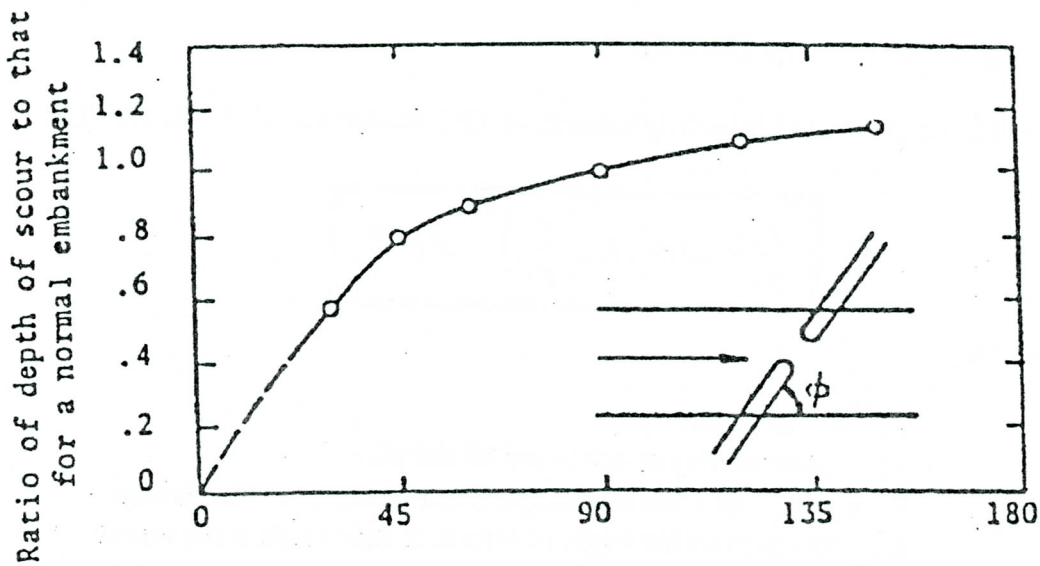
Where:

y_s = scour depth
y_1 = flow depth just upstream of the pier
K_1 = correction for pier shape from figure and table below
K_2 = correction for angle of attack of flow from table below
a = pier width
l = pier length
Fr_1 = Froude number = $\frac{V_1}{(gy_1)^{0.5}}$

$$y_s = 4 Fr_1^{0.33}$$

Where: y_s = equilibrium depth of scour
y_1 = average upstream flow depth in main channel
Fr_1 = upstream Froude number

CASE 6: ABUTMENT LENGTH TO FLOW DEPTH RATIO (a/y_1) GREATER THAN 25



CASE 7: ABUTMENT SET AT AN ANGLE, ϕ, TO THE FLOW

IV. FROEHLICH'S EQUATION (STEP 5)

A. Live-bed scour at an abutment.

Froehlich (1989) analyzed 170 live-bed scour measurements in laboratory flumes to obtain the following equation:

Factor of Safety

$$\frac{y_s}{y_1} = 2.27 K_1 K_2 \left(\frac{a'}{y_1}\right)^{0.43} Fr_1^{0.61} + 1$$

use practical limit of 25.
see pg 16-19.

Where: K_1 = coefficient for abutment shape

K_2 = coefficient for angle of embankment to flow

$$K_2 = (\theta/90)^{0.13}$$

$< 90^o$ if embankment points downstream

$> 90^o$ if embankment points upstream

a' = length of abutment projected normal to flow

$$a' = A_e/Y_1$$

A_e = the flow area of the approach cross section obstructed by the embankment

Fr_e = Froude number of approach flow upstream of the abutment

$$= V_e/(gy_1)^{0.5}$$

$V_e = Q_e/A_e$

Q_e = the flow obstructed by the abutment and approach embankment

y_1 = depth of flow at the abutment

y_s = scour depth

Description	K_1
Vertical Abutment	1.0
Vertical Abutment with Wing Walls	0.82
Spill Through Abutment	0.55

B. The constant term unity (+1) in Froehlich's equation is a safety factor that makes the equation predict a scour depth larger than any of the measured scour depths in the experiments. This safety factor should be used in design.

C. Froehlich suggested that scour depth be increased by $y_1/6$ if there are dunes in the main channel upstream of the abutment.

D. **Clear-water scour at an abutment.**

Froehlich using dimensional analysis and multiple regression analysis of 164 clear-water scour measurements in laboratory flumes developed an equation FOR CLEAR WATER SCOUR. IT IS NOT RECOMMENDED FOR USE BECAUSE THE POTENTIAL DECREASE IN SCOUR DEPTH AT ABUTMENTS RESULTING FROM COARSER MATERIAL IS NOT KNOWN.

Computation 2 for right abutment.

Assume: Depths and velocities is measured from the top of the bank to the water surface (2.0 ft.).

$K_1 =$ 0.55

$$K_2 = \left(\frac{80}{90}\right)^{0.13} = 0.98$$

$$a' = \left(\frac{52 \text{ ft} \times 2 \text{ ft}}{2 \text{ ft}}\right) = 52.0 \text{ ft}$$

$$V_e = \left(\frac{70 \text{ cfs}}{52 \text{ ft} \times 2 \text{ ft}}\right) = 0.67 \text{ f/s}$$

$$Fr = \frac{0.67 \text{ f/s}}{(32.2 \text{ f/s}^2 \times 2.0 \text{ ft})^{0.5}} = 0.08$$

$$\boxed{\frac{y_s}{(2.0)} = 2.27 \times (0.55) \times (0.98) \times \left(\frac{\cancel{52.0}\ 25}{2.0}\right)^{0.43} \times (0.08)^{0.61} + 1}$$

$$\frac{y_s}{(2.0)} = 2.05$$

Therefore, scour at the right abutment is:

$y_s =$ 4.1 ft

LESSON 16

ESTIMATING SCOUR AT HIGHWAY BRIDGES

TOTAL SCOUR

I. TOTAL SCOUR

A. Step 7 of design/evaluation process (HEC-18).

B. Long-term changes (aggradation or degradation).

1. Long-term changes (aggradation or degradation).

2. Contraction scour.

3. Local scour.

$$Total\,Scour\,\Delta Z_T = \Delta Z_D + \Delta Z_C + \Delta Z_L$$

$$Where\,D = Degradation\,(or\,aggradation),\ \Delta Z_c = Contraction\,scour,\ and\ \Delta Z_L = Local\,Scour$$

II. PLOT TOTAL SCOUR

A. Plot cross section of channel and floodplain at bridge. Use distorted (vertical) scale.

B. Plot aggradation (+) or degradation (-) from existing bed line.

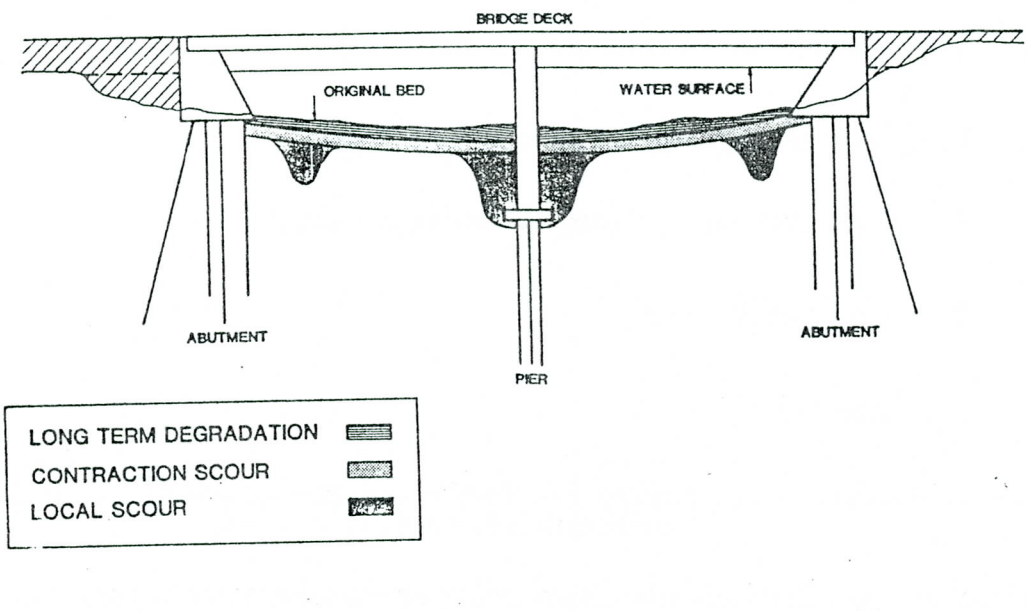
C. Plot contraction scour from and below aggradation or degradation level.

D. Plot local scour from and below contraction scour line.

E. Plot depth of scour at each pier and abutment, and estimate and plot width of scour holes.

1. Assume base of scour hole 5 feet wider than pier and use angle of repose (30 degrees for sand) to get side slopes of hole, or

2. Assume width of top of scour hole is 2.75 times the scour depth.



DEFINITION SKETCH - TOTAL SCOUR

F. Other factors:

1. Is debris a problem in the basin? Is debris build up on piers likely? If so, consider increasing pier width in local scour equations an amount equal to anticipated debris accumulation and recalculate pier scour.

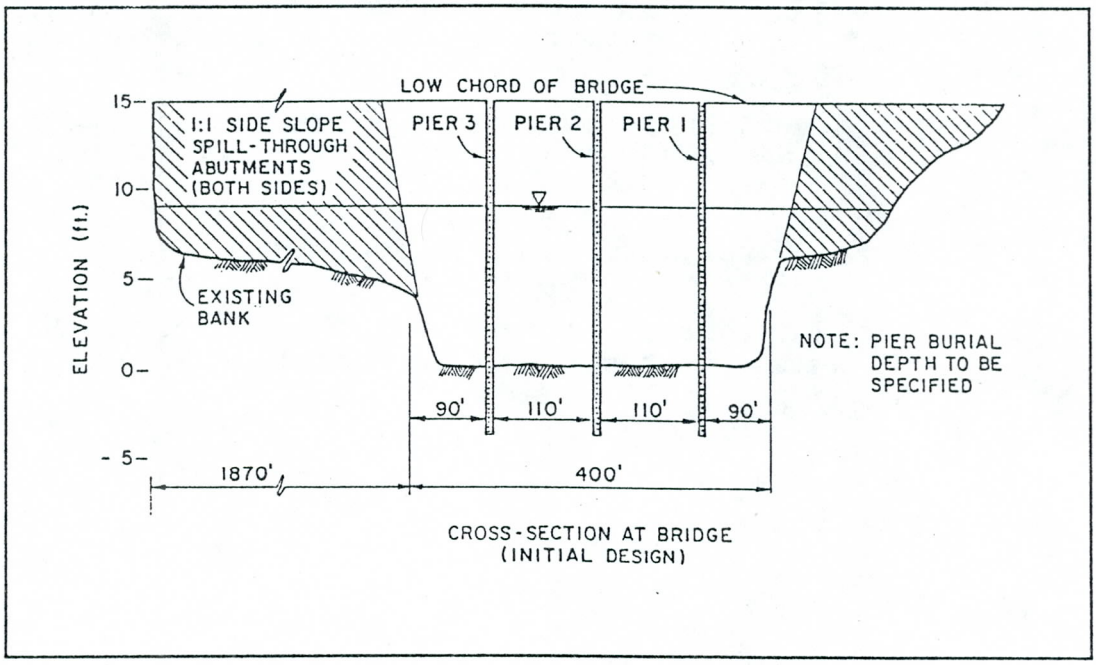
III. EVALUATE RESULTS

A. Scour depths reasonable and consistent with experience?

B. Do scour holes intersect?

1. Consider increasing length of bridge opening.

4. Description of bridge.



DEFINITION SKETCH - LOCATION OF PIERS AND ABUTMENTS

These design parameters may require modification after total scour is estimated.

a. Average bottom width =398 ft.

b. Piers.

Number of piers = 3
Center pier in center of channel.
Span between piers = 110 ft.
Span from piers to abutments = 90 ft.
(Note: piers will be numbered from the right bank)

Pier Width = 3 ft. (Round Nose)

Pier Length = 36 ft.

Pier Footing:
Width = 7 ft.
Length = 41 ft. (Initial design calls for setting top of pile caps or footings 2 ft. below average bed elevation after accounting for contraction scour)

c. Abutments.

Abutments are spill through with 1:1 slope.
The toe of the abutments are to be set at the edge of the bank.

d. Bridge deck.

Bottom cord of bridge is 8 ft above banks (15 ft above the average channel bed).

e. Hydraulic conditions for initial bridge design.

Hydraulic conditions in the bridge opening will be determined after assessing contraction scour. However, the bridge must pass Q_{100}=43,600 cfs.

D. <u>Step 4</u> - Determine contraction scour.

1. General equation.

$$\frac{y_2}{y_1} = \left\{\frac{Q_t}{Q_c}\right\}^{\frac{6}{7}} \left\{\frac{W_1}{W_2}\right\}^{K_1} \left\{\frac{n_2}{n_1}\right\}^{K_2}$$

$$y_s = y_2 - y_1$$

$y_1 =$ Average depth in the main channel

$y_2 =$ Average depth in the contracted section

$W_1 =$ Bottom width of the main channel

$W_2 =$ Bottom width of the contracted section

$Q_c =$ Discharge in the main channel

$Q_t =$ Discharge in the contracted section

$n_1 =$ Manning n in the main channel

$n_2 =$ Manning n in the contracted section

$\frac{V_{*c}}{w}$	e	K_1	K_2	Mode of Bed Material Transport
< 0.5	0.25	0.59	0.066	Mostly Contact Bed Material
0.5 to 2.0	1.0	0.64	0.21	Some Suspended Bed Material
> 2.0	2.25	0.69	0.37	Mostly Suspended Bed Material

2. Determine K_1 and K_2.

Note:

These parameters are based on the flow conditions in the main channel of the unobstructed reach.

Average Width = 398 ft.

Depth = 9 ft.

Hydraulic Radius, R = Area/Wetted Perimeter = 8.61 ft.

Discharge in main channel Q_{100} = 25,890 cfs.

Average Velocity in main channel = 7.23 f/s.

Average Shear Stress:

$$\tau = \gamma R S$$

$$\tau = 62.4\, lb/ft^3 \times 8.61\, ft \times 0.00076 = 0.408\, lb/ft^2$$

Shear Velocity:

$$V_{*c} = \left(\frac{\tau}{\rho}\right)^{0.5}$$

$$V_{*c} = \left(\frac{0.408}{1.94}\right)^{0.5} = 0.46\, f/s$$

Compute $\frac{V_{*c}}{w}$:

$$\frac{V_{*c}}{w} = \left(\frac{0.46\ f/s}{0.13\ f/s}\right) = 3.53$$

K_1 and K_2 from Table:

K_1 = 0.69 K_2 = 0.37

c. Overbank conditions at abutments (overbank).

	Left Overbank	Right Overbank
Velocity f/s V_a	3.38	0.67
Depth @ abutment ft y_a (using overbank parameters)	4.8	2.0
Average depth ft.	2.8	2.0

2. General equation for local scour at abutments.

$$\frac{y_s}{y_a} = 2.27 K_1 K_2 \left(\frac{a'}{y_a}\right)^{0.43} Fr^{0.61} + 1.0$$

y_a = Flow depth at abutment

y_s = Scour depth

K_1 = Coefficient for abutment shape
(For spill through $k_1 = 0.55$ Table 4.1 HEC-18)

$$K_2 = \left(\frac{\Theta}{90}\right)^{0.13}$$

$$a' = \frac{A_e}{y_a}$$

A_e = Flow area obstructed by embankment
This is the product of the floodplain width and average depth in the floodplain.

$$Fr = \frac{V_e}{(g y_a)^{0.5}}$$

$$V_e = \frac{Q_e}{A_e}$$

FS = Safety Factor = 1.0

Q_e = Flow obstructed by the abutment and approach.

3. **Computations.**

a. **Left abutment.**

Computation 1 for left abutment.

Assume: Depth at abutment y_a is measured from the top of bank to the water surface (4.8 ft.).

$K_1 =$ 0.55

$$K_2 = \left(\frac{100^\circ}{90^\circ}\right)^{0.13} = 1.01$$

$$a' = \left(\frac{2.8 \text{ ft} \times 1870 \text{ ft}}{4.8 \text{ ft}}\right) = 1091 \text{ ft}$$

$$V_o = \left(\frac{17{,}700 \text{ cfs}}{1870 \text{ ft} \times 2.8 \text{ ft}}\right) = 3.38 \text{ f/s}$$

$$Fr = \frac{3.38 \text{ f/s}}{(32.2 \text{ f/s}^2 \times 4.8 \text{ ft})^{0.5}} = 0.27$$

$$\boxed{\frac{y_s}{(4.8)} = 2.27 \times (0.55) \times (1.01) \times \left(\frac{1091}{4.8}\right)^{0.43} \times (0.27)^{0.61+1}}$$

$$\frac{y_s}{(4.8)} = 6.85$$

Therefore, scour at the left abutment is:

$y_s =$ 32.88 ft

$\left(\frac{1091}{4.8}\right)^{0.43} = 227^{0.43} = 10.31$ whereas if one limits the ratio to 25, $25^{0.43} = 3.99$ or only 39% of the abutment scour as calculated by Froehlich. Instructor's suggestion was to get a jurisdictional limit of a'/y_a. This is due to an asymptotic effect of y_s with a', i.e., abutment scour does have a "practical" maximum.

For $y_a = 9.0$ ft, $y_s = 33.7$ ft, not much change.

Computation 2 for left abutment.

Assume: Depth at abutment y_a is measured from the bottom of the channel at toe of the abutment to the water surface (9.0 ft.).

$K_1 =$ 0.55

$$K_2 = \left(\frac{80}{90}\right)^{0.13} = 0.98$$

$$a' = \left(\frac{2.0 \text{ ft} \times 52 \text{ ft}}{9.0 \text{ ft}}\right) = 11.56 \text{ ft}$$

$$V_o = \left(\frac{70 \text{ cfs}}{52 \text{ ft} \times 2.0 \text{ ft}}\right) = 0.67 \text{ f/s}$$

$$Fr = \frac{0.67 \text{ f/s}}{(32.2 \text{ f/s}^2 \times 9.0 \text{ ft})^{0.5}} = 0.04$$

$$\boxed{\frac{y_s}{(9.0)} = 2.27 \times (0.55) \times (0.98) \times \left(\frac{11.56}{9.0}\right)^{0.43} \times (0.04)^{0.61} + 1}$$

$$\frac{y_s}{(9.0)} = 1.19$$

Therefore, scour at the left abutment is:

$y_s =$ 10.72 ft

Computation 2 for right abutment.

Assume: Depths and velocities is measured from the top of the bank to the water surface (2.0 ft.).

$K_1 =$ 0.55

$$K_2 = \left(\frac{80}{90} \right)^{0.13} = 0.98$$

$$a' = \left(\frac{52 \text{ ft} \times 2 \text{ ft}}{2 \text{ ft}} \right) = 52.0 \text{ ft}$$

$$V_e = \left(\frac{70 \text{ cfs}}{52 \text{ ft} \times 2 \text{ ft}} \right) = 0.67 \text{ f/s}$$

$$Fr = \frac{0.67 \text{ f/s}}{(32.2 \text{ f/s}^2 \times 2.0 \text{ ft})^{0.5}} = 0.08$$

$$\boxed{\frac{y_s}{(2.0)} = 2.27 \times (0.55) \times (0.98) \times \left(\frac{\cancel{52.0}}{2.0} \right)^{0.43} \times (0.08)^{0.61} + 1}$$

25

$$\frac{y_s}{(2.0)} = 2.05$$

Therefore, scour at the right abutment is:

$y_s =$ 4.1 ft

b. Pier 3.

$$Fr_1 = \frac{\overbrace{12.4 \times 1.2}^{14.9} \ f/s}{(32.2 \ f/s^2 \ x \ 9.0 \ ft)^{0.5}} = 0.88$$

For round nose piers:

$K_1 = 1.0$

$$\frac{L}{a} = \frac{(36 \ ft)}{(3 \ ft)} = 12.0$$

From table:

$K_2 = 1.5$

$$\boxed{\frac{y_s}{(9.0)} = 2.0 \times (1.0) \times (1.5) \times \left(\frac{(3.0)}{(9.0)}\right)^{0.65} \times (0.88)^{0.43}}$$

$$\frac{y_s}{(9.0)} = 1.39$$

$y_s = 12.48 \ ft$

Therefore, the estimated pier scour corrected for possible antidune flow at Pier 3 is:

$y_s = 12.48 \times 1.10 = 13.73 \ ft$

F. <u>Step 6</u> - Local scour at piers.

1. Variables for estimation of local scour at piers.

Left Bank	Pier 3	Pier 2	Pier 1	Right Bank
V_1 (f/s)	14.9	12.4	12.4	
Velocity Coeff. (see note)	1.2	1.0	1.0	
y_1 (ft)	9.0	9.0	9.0	
Angle of Attack	5°	0°	0°	

Velocity is determined by multiplying mean velocity by a coefficient presented in table above.

2. General equation.

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

$K_1 =$ Correction coefficient for pier shape.
($K_1 = 1.0$ for round nose from Table 4-3 HEC-18)

$K_2 =$ Correction coefficient for angle of piers skewed to the flow.
(Table 4-4 HEC-18)

$a =$ width of the pier

$Fr = \frac{V_1}{(gy_1)^{0.5}}$

3. **Computations.**

a. **Pier 1 and Pier 2.**

$$Fr_1 = \frac{12.4 \quad f/s}{(32.2 \quad f/s^2 \quad x \quad 9.0 \quad ft)^{0.5}} = \underline{0.73}$$

For round nose piers:

$K_1 = 1.0$

For zero angle of attack:

$K_2 = \underline{1.0}$

$$\boxed{\frac{y_s}{(9.0)} = 2.0 \times (1.0) \times (1.0) \times \left(\frac{(3.0)}{(9.0)}\right)^{0.65} \times (0.73)^{0.43}}$$

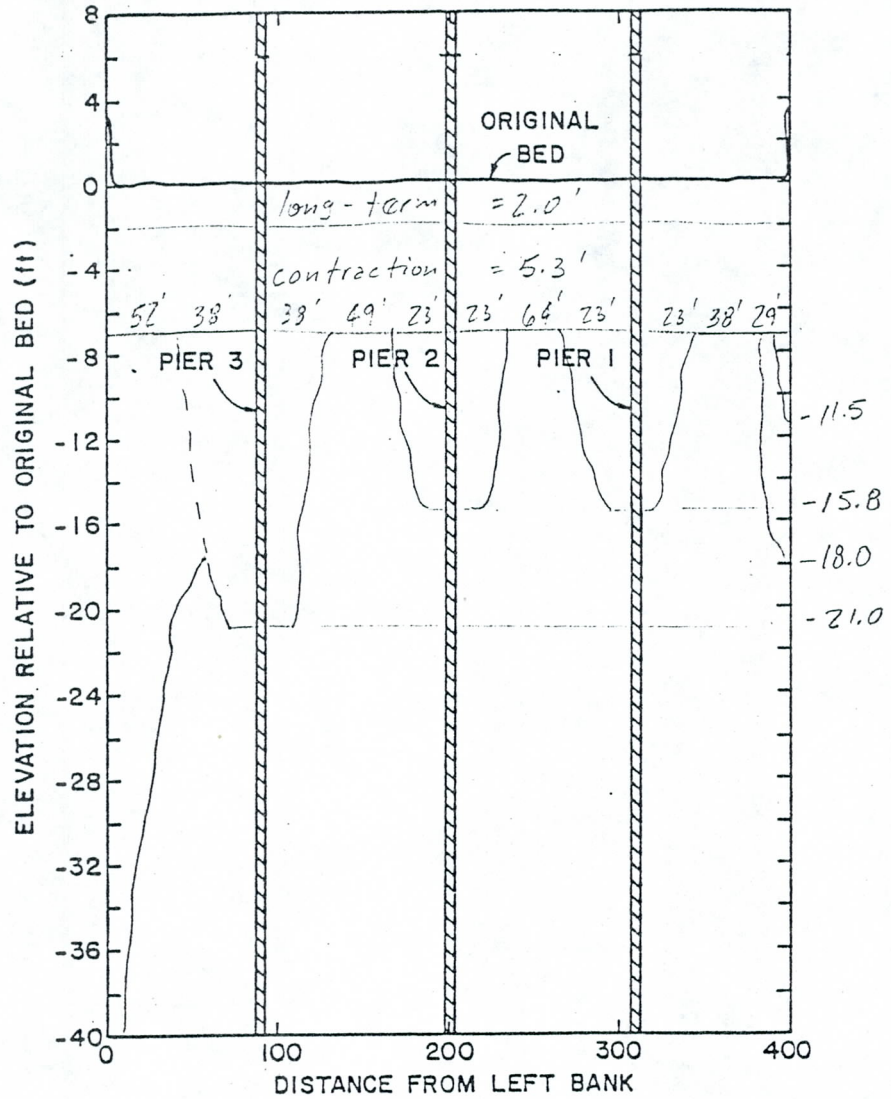
$$\frac{y_s}{(9.0)} = \underline{0.855}$$

$y_s = \underline{7.69}$ ft

Therefore, the estimated pier scour corrected for possible antidune flow at Pier 1 and 2 is:

$y_s = \underline{7.69} \times \underline{1.10} = \underline{8.46}$ ft

G. Sketch the long-term bed elevation change, the contraction scour, and the local scour at the abutments and piers on the attached figure.



SKETCH OF TOTAL SCOUR