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Administration

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SCOUR MONITORING AND INSTRUMENTATION

Demonstration Project 97

Office of Technology Applications
Federal Highway Administration
400 Seventh Street, S.W.
Washington, D.C. 20590

Participant's Workbook

SCOUR MONITORING AND INSTRUMENTATION
DEMONSTRATION PROJECT 97

PARTICIPANT OVERVIEW

PURPOSE

Bridge scour has become a topic of nationwide interest in recent years, and significant progress has been made in all aspects of the bridge scour problem. One area where concentrated research has occurred is scour instrumentation and development of techniques suitable for bridge scour monitoring and measurement. The research and progress that has been made in bridge scour instrumentation will be a tremendous asset once the technology that has been developed is integrated into the highway community.

To facilitate the technology transfer of instrumentation related research to the highway industry, particularly those in inspection and maintenance operations, the Federal Highway Administration (FHWA) has developed this Demonstration Project on scour monitoring and instrumentation. Unlike traditional training courses or many short courses, FHWA Demonstration Projects are specifically designed to incorporate physical demonstration and/or hands-on experience to support and enhance classroom or lecture presentations. *The purpose of Demonstration Project 97 is to promote the use of new and innovative equipment to measure scour, monitor changes in scour over time, detect the extent of past scour and serve as countermeasures.*

ORGANIZATION

Demonstration Project 97 is based around a one and one-half day workshop that includes instructional modules on *fixed instrumentation, portable instrumentation, and positioning systems*. For each type of instrumentation an introductory lecture is presented, followed by a workshop based demonstration. The first morning includes an Introduction and sessions that review scour and stream stability processes (Lesson 1) and bridge inspection (Lesson 2). The closing sessions include an overview of monitoring programs (Lesson 6) and the course summary and critique (Lesson 7). As discussed in Lesson 7, an optional one and one-half days for field demonstration may be scheduled, but is not a part of the core curriculum.

The workshops will be completed primarily in a laboratory type setting, using workstations where the instrument and assorted photographs, videos, graphics, and handouts will be available. Equipment demonstrations occur in Lessons 3, 4, and 5. You will have ample opportunity for "hands-on" experience during the demonstrations. The equipment selected for demonstration is, generally speaking, available "off-the-shelf," and has been field-tested and used for scour monitoring. One-of-a-kind and other new and innovative equipment is discussed in the course, but not demonstrated.

RESOURCES

A detailed schedule has been provided. The Participant Notebook contains all the information that will be presented in the classroom lecture, with enough blank space for additional notes. The slide images that you see during the lecture, are also reproduced in the notebook. For the demonstration sessions, you may want to bring your workbook for recording additional notes or observations.

August 21, 1998

SCOUR MONITORING AND INSTRUMENTATION DEMONSTRATION PROJECT 97 DETAILED LESSON SCHEDULE

Day	Time	Length (min.)	Lesson	Topic	Method of Instruction	Resources
INTRODUCTION						
1	8:00-9:00	60	Introduction	Overview of DP-97	Lecture	Lesson outline slides
REVIEW OF SCOUR, STREAM STABILITY, AND INSPECTION CONCEPTS						
1	9:00-10:00	60	1	Scour at Highway Bridges	Lecture	Lesson outline, slides, video
	10:00-10:15	15		Break		
	10:15-11:00	45	2	Bridge Inspection	Lecture	Lesson outline, slides,video
FIXED INSTRUMENTATION						
1	11:00-12:00	60	3	Overview of Fixed Instrumentation	Lecture	Lesson outline slides, video
	12:00- 1:00	60		Lunch		
	1:00- 2:30	90	3	Demonstration of Fixed Instrumentation	Workshop	Lesson outline
	2:30-2:45	15		Break		
PORTABLE INSTRUMENTATION						
1	2:45- 3:30	45	4	Overview of Portable Instrumentation	Lecture	Lesson outline slides
	3:30-4:00	30	4	Demonstration of Portable Instrumentation	Workshop	Lesson outline
POSITIONING SYSTEMS						
2	8:00- 9:00	60	5	Overview of Positioning Methods	Lecture	Lesson outline slides
	9:00-10:00	60	5	Demonstration of Positioning Methods	Workshop	
	10:00-10:15	15		Break		
IMPLEMENTATION						
2	10:15-11:15	60	6	Monitoring Program	Lecture	Lesson outline
	11:15-11:45	30	7	Course Summary/Critique		
	1:00- 5:00			Optional Field Trip		
3	8:00- 5:00			Optional Field Trip		

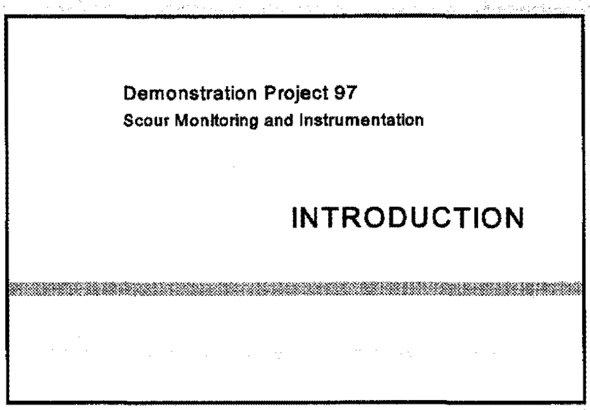
INTRODUCTION

OVERVIEW: Method of Instruction: Lecture

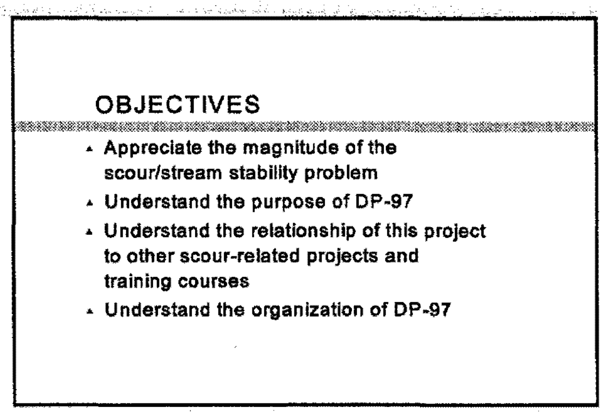
Lesson Length: 60 minutes

Resources:

Lesson Outline
Slides



I.0 Title



I.1 Objectives

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

1. **Appreciate** the magnitude of the scour/stream stability problem.

2. **Understand** the purpose of DP97.

3. **Understand** the relationship of this project to other scour-related projects and training courses.

4. **Understand** organization of DP97.

INTRODUCTION

I. HOST WELCOME

II. INTRODUCTION OF INSTRUCTORS

III. MAGNITUDE OF THE BRIDGE SCOUR/STREAM STABILITY PROBLEM

IV. PURPOSE OF DP-97

V. RELATIONSHIP OF DP-97 TO OTHER BRIDGE SCOUR-RELATED PROJECTS

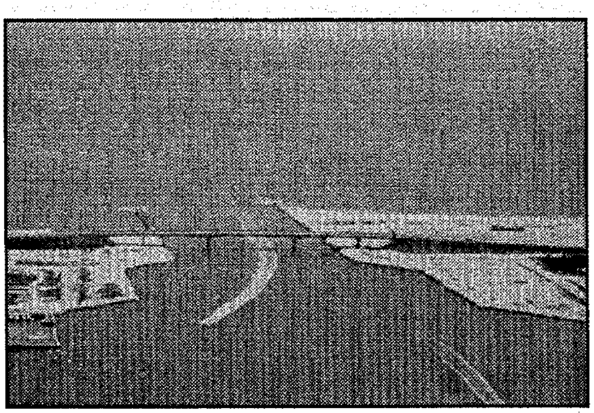
VI. CATEGORIES OF INSTRUMENTS

VII. ORGANIZATION AND OBJECTIVES OF DP-97

SCOUR MONITORING AND INSTRUMENTATION

DEMONSTRATION PROJECT 97

INTRODUCTION



I.2 Indian River inlet, Delaware

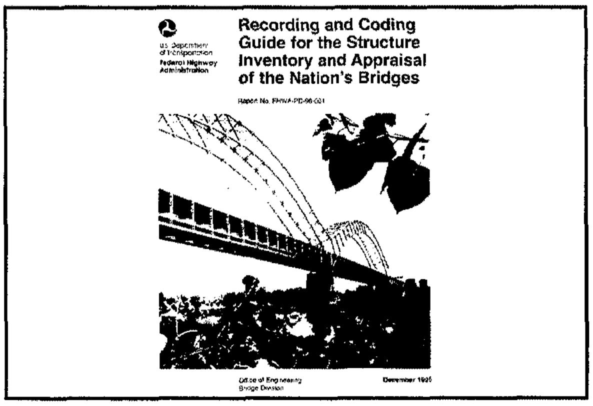
I. HOST WELCOME

II. INTRODUCTION OF INSTRUCTORS

III. MAGNITUDE OF THE BRIDGE SCOUR/STREAM STABILITY PROBLEM

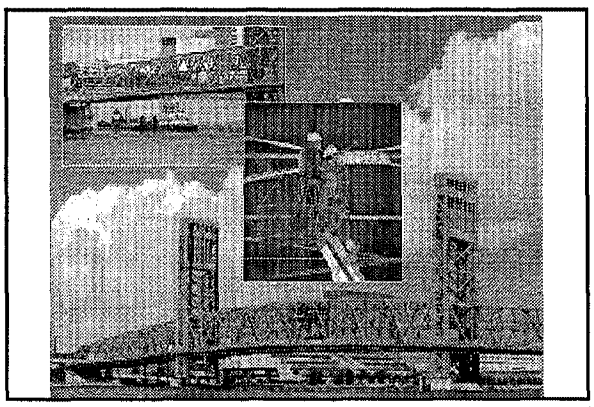
A. Scour and stream stability problems occur due to the erosive action of flowing water. The resulting vertical and lateral changes in channel dimensions can jeopardize bridge foundations and integrity.

B. There are over 575,000 bridges in the National Bridge Inventory - about 84 percent are over waterways (roughly 485,000 bridges).



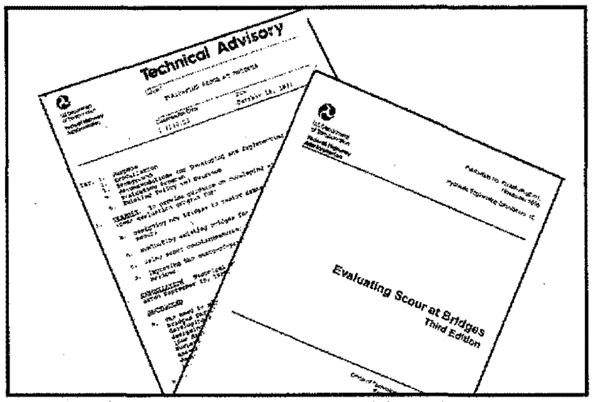
I.3 Recording and Coding Guide

C. Item 113 of the Recording and Coding Guide for the Structural Inventory and Appraisal of the Nations Bridges ("Coding Guide") requires States to identify the current status of bridges regarding vulnerability to scour.



I.4 Bridge inspection crew at work

1. Technical Advisory T 5140.23, "Scour at Bridges" (issued October 28, 1991) gives guidance on developing and implementing a scour evaluation program which is needed to code item 113.



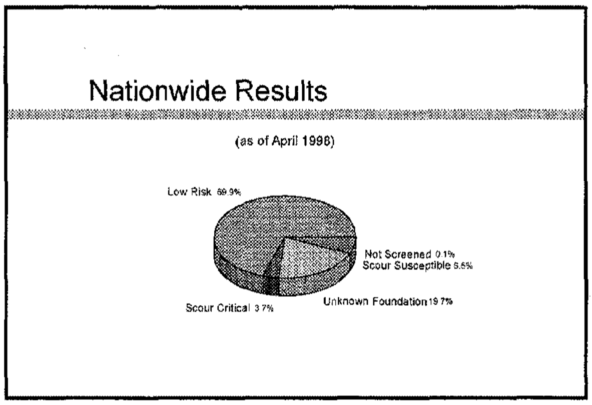
I.5 T 5140.23 and HEC-18

2. Evaluations referred to in Technical Advisory T 5140.23 are to be completed by an interdisciplinary team according to the procedures given in Hydraulic Engineering Circular (HEC) No. 18, "Evaluating Scour at Bridges," FHWA-IP-90-017, dated November 1995.

3. HEC-18 recommends that States screen bridges into five categories: low-risk, scour-susceptible, scour critical, unknown foundations, or tidal.

4. After screening, all bridges identified as scour-susceptible are to be evaluated to determine if they are scour-critical. This evaluation is based on field and office scour analysis. The target date for completing these scour evaluations was January 1, 1997.

5. In general terms, low-risk bridges have little potential for scour or stream instability problems. Based on screening, bridges that are considered particularly vulnerable to scour failure are categorized scour-susceptible. Scour-critical bridges are those that have an existing scour/stream instability problem (based on field observations), or based on scour calculations that show the bridge to be scour-critical at the 500-year flood condition.



I.6 Pie-chart showing screening results

6. As of April, 1998, 99.9 percent of the approximately 485,000 bridges over water have been screened into the following categories:

Categories	Number of Bridges	Percentage
Low risk	338,555	69.9%
Scour Critical	18,088	3.7%
Unknown Foundation	95,574	19.7%
Scour susceptible	31,532	6.5%
Not Screened	315	0.1%
TOTALS	484,064	99.9%

SCOUR CRITICAL BRIDGES

- Require a plan of action
- Plan of action must include instructions on type and frequency of inspections
- Dive inpection is valuable, but can be limited by visability and high current
- Instrumentation introduced during this Demonstration Project provides additional tools for scour monitoring

I.7 Scour-critical bridges

7. Bridges identified as scour-critical (based on office or field review) require a Plan of Action for addressing the scour problems. The plan of action for scour-critical bridges must include instructions regarding the type and frequency of inspections.

8. Diver inspection can be, and has been, used for scour inspection; however, visibility and high current during flood conditions (when the greatest scour is typically occurring) can limit the use of divers. Instrumentation discussed during this Demonstration Project provides additional tools that can be used for scour measurement and monitoring.

BRIDGE FAILURES

- 60 percent of bridge failures are due to scour and stream instability
- Annual cost of bridge failures is about $30 million, not including indirect costs incurred when bridges and roads are closed
- 1987 Schoharie Creek failure result of local scour; 1989 Hatchie River failure result of stream instability
- Many other failures have occurred

I.8 Bridge failures

D. Scour and stream stability problems cause 60% of the bridge failures in the United States.

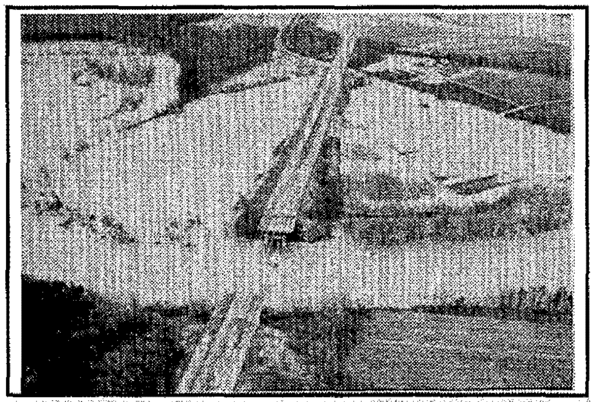
E. For bridges on the Federal Aid system, the annual cost for scour-related bridge failures is about $30 million, and the flood damage repair costs for highways are about $50 million. These costs do not include the indirect losses incurred by the local economy when bridges and roads are closed.

F. Two highly publicized failures were the 1987 Schoharie Creek bridge failure and the 1989 Hatchie River bridge failure.

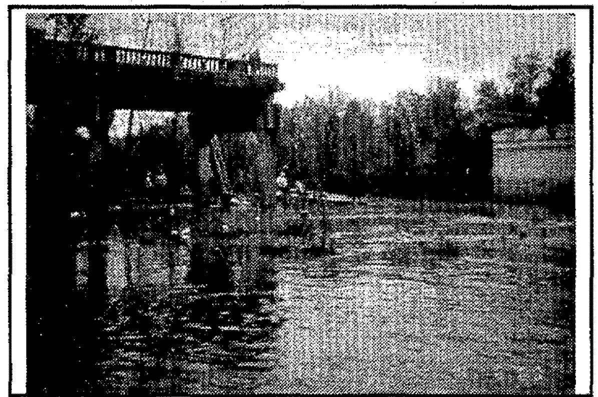
   1. The Schoharie Creek failure was due to local scour, while the Hatchie failure was primarily due to lateral migration and stream instability.

   2. However, many other bridges have failed, or were threatened by failure, during other recent flood events. The following slides illustrate many of these failures.

NOTES:

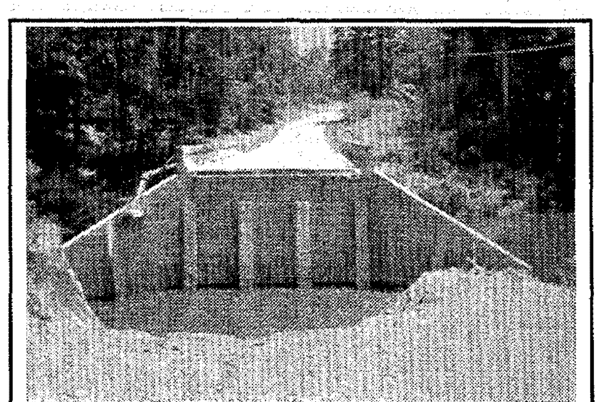


I.9a 1987 Schoharie Creek Bridge failure

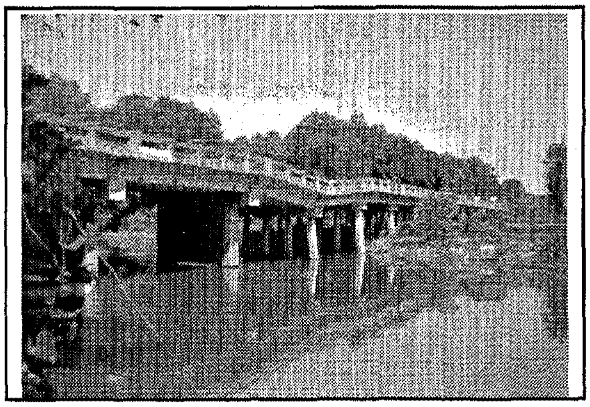


I.9b 1989 Hatchie bridge failure

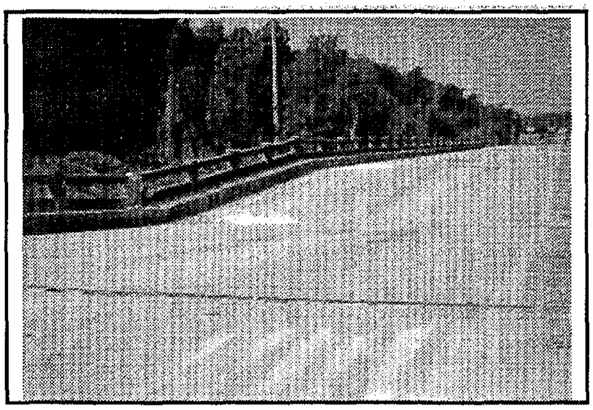
I.9c Hatchie bridge failure



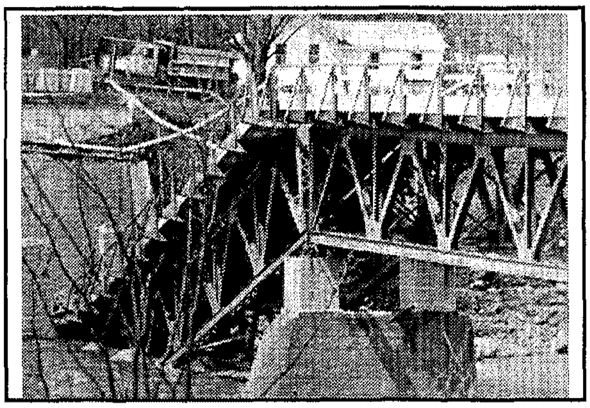
I.9d 1994 Georgia flooding



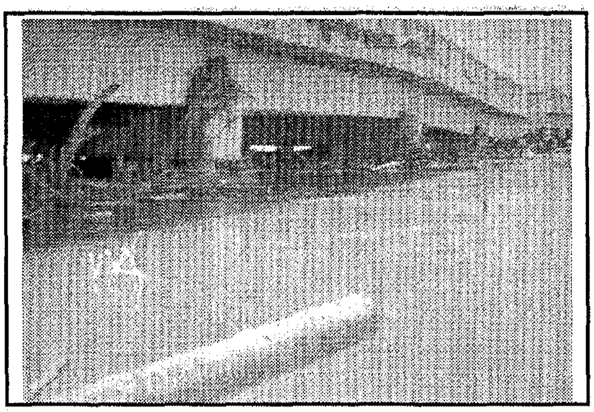
I.9e 1994 Georgia flooding



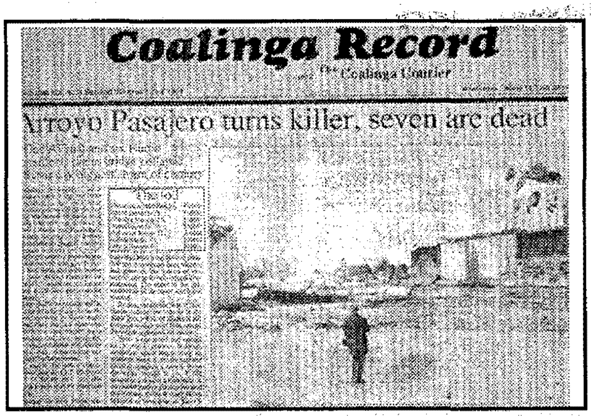
I.9f 1994 Georgia flooding



I.9g Mill Point bridge, Schoharie Creek, NY



I.9h Henry's Fork, Idaho, during Teton Dam failure

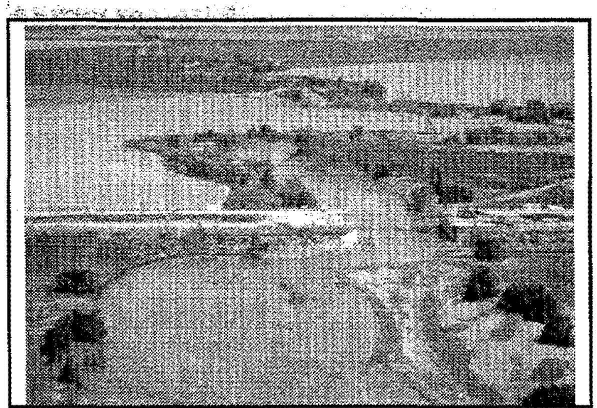


Coalinga Record

The Coalinga Courier

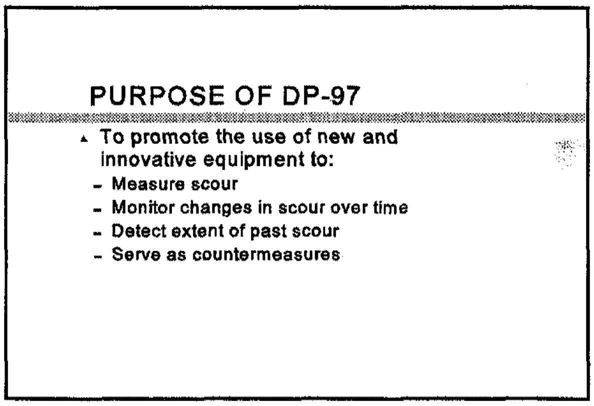
Arroyo Pasajero turns killer, seven are dead

I.9i Arroyo Pasajero headlines



I.9j Failure of two I-5 bridges over Arroyo Pasajero

IV. PURPOSE OF DP-97



I.10 Course purpose

The purpose of DP-97 is to promote the use of new and innovative equipment to:

A. Measure scour.

B. Monitor changes in scour over time.

C. Detect extent of past scour.

D. Serve as countermeasures for scour-critical bridges.

V. RELATIONSHIP OF DP-97 TO OTHER BRIDGE SCOUR-RELATED PROJECTS

RELATED PROJECTS

- Highways in the River Environment (HIRE)
- Stream Stability and Scour Training Course
- Underwater Inspection of Bridges (DP80)
- Underwater Evaluation and Repair of Bridge Components (DP98)

I.11a Related projects

A. Highways in the River Environment (HIRE) - National Highway Institute (NHI) short course 13010 providing a broad-based overview of hydraulic and sediment transport principles important to highway engineering.

B. Stream Stability and Scour Training Course - National Highway Institute short course 13046 providing more of a "how-to" approach to bridge scour and stream stability analysis based on Hydraulic Engineering Circular Nos. 18 and 20 and Technical Advisory T5140.23. A module on scour countermeasures is available, covering HEC-23.

C. Underwater Inspection of Bridges, Demonstration Project No. 80 - A previous Demonstration Project that provided specific guidance on specialized bridge inspection procedures, and that emphasized underwater inspection techniques.

D. Underwater Evaluation and Repair of Bridge Components, Demonstration Project No. 98 - A new Demonstration Project that emphasizes bridge evaluation and repair information. An updated, shortened version of DP80 will also be available through DP-98.

RELATED PROJECTS (cont.)

- NCHRP Projects
  - Instruments for Measuring Scour at Bridge Piers and Abutments (21-3)
  - Determination of Unknown Subsurface Bridge Foundations (21-5)
  - Expert System for Stream Stability and Scour Evaluation (24-6)
  - Alternative Countermeasures for Pier Scour (24-7)
  - Scour at Bridge Foundations (24-8)

I.11b Related projects (cont)

E. National Cooperative Highway Research Program (NCHRP) Projects.

1. Instruments for Measuring Scour at Bridge Piers and Abutments (Project 21-3). A research project that developed fixed instrumentation to measure maximum scour depths at bridge piers and abutments.

2. Determination of Unknown Subsurface Bridge Foundations (Project 21-5). A research project to develop nondestructive testing procedures to determine unknown subsurface bridge foundations. The FHWA Geotechnical Guideline No. 16 summarizes the NCHRP 21-5 Interim Report.

3. Expert System for Stream Stability and Scour Evaluation (Project 24-6). A research project that developed an expert system for bridge scour evaluation. The program, CAESAR, and a user manual may be downloaded from "www.ce.washington.edu/~scour."

4. Alternative Countermeasures for Pier Scour (Project 24-7). A research project to investigate ways to control or limit pier scour.

5. Scour at Bridge Foundations (Project 24-8). A project to develop a balanced and comprehensive strategic plan for fundamental and applied research on bridge scour and stream instability.

RELATED PROJECTS (cont.)

- USGS projects conducted in cooperation with FHWA and state DOT's
  - Instrumentation development
  - National Data Repository
  - Data Collection
  - Debris production research
  - Scour assessments and evaluations
  - Scour monitoring
  - Modeling

I.11c USGS/FHWA/DOT research

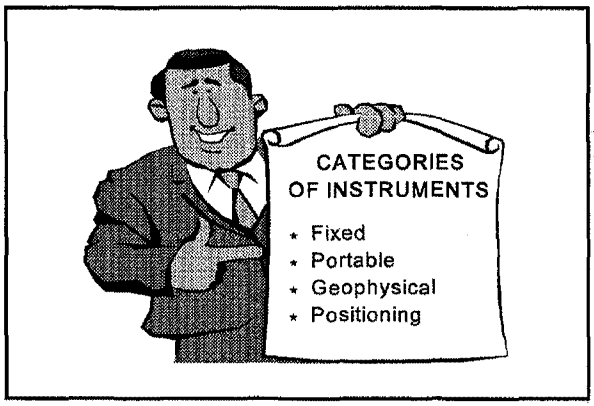
H. USGS scour research and programs conducted jointly and/or funded by FHWA and individual state programs, including:

<u>USGS Bridge Scour Projects</u>

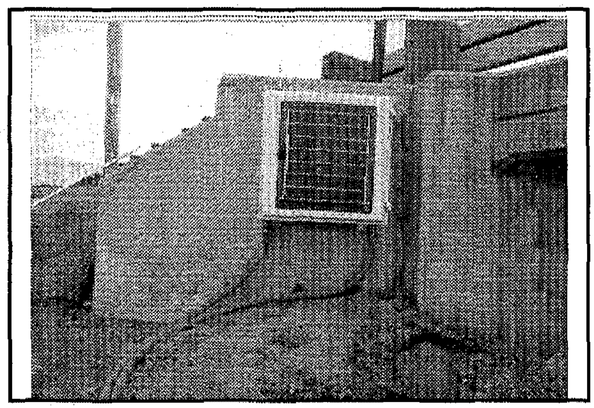
FHWA Sponsored	-Instrumentation development -National Data Repository -Detailed data collection -Debris production research -Modeling
State DOT Sponsored	-Scour assessments and evaluations -Scour monitoring-fixed and portable -Limited-detailed data collection -Modeling

VI. CATEGORIES OF INSTRUMENTS

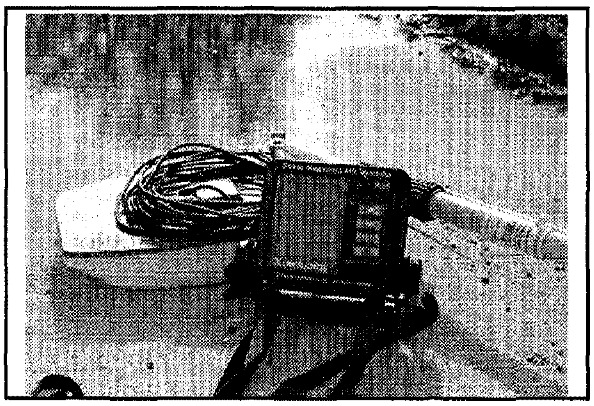
A. There are four primarily categories of instruments/monitoring.



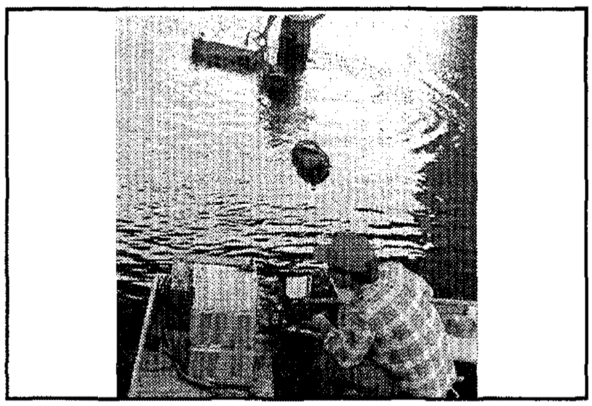
I.12 Categories of instruments and monitoring



I.13 Instrument shelter for fixed instruments



I.14 Portable instrument



I.15 Geophysical instrument

I.16 Position system

1. Fixed.

   - Instruments are installed and left at the bridge
   - Often include a data logger
   - Will monitor only where instrument is installed, which may not be where scour is occurring

2. Portable.

   - Instruments are taken to a bridge and used to measure one or many locations
   - Deployed from the bridge or from a boat
   - Provides real-time data only

3. Geophysical.

   - Instruments are "portable" in the sense that they are taken from one bridge to another, but not generally used for real-time data
   - Most useful for forensic purposes (e.g. could not get to all bridges during the flood, but went back later with geophysical instruments to evaluate what might have happened...)
   - Require calibration and experience to obtain good results

4. Positioning methods.

- Provide location information, particularly for portable and geophysical instrumentation
- Range from an approximate location based on bridge characteristics to very precise surveyed information using laser and GPS systems

TOOLBOX CONCEPT

- No single instrument will work in all situations
- Different instrument types can be complimentary

I.17 Toolbox concept

B. Toolbox approach - No single instrument is available that can be utilized in all situations encountered in the field. Furthermore, all instrument types are complimentary, e.g., operation of fixed instruments should be verified using portable instruments; deploying portable instruments during a flood can be dangerous requiring the use of geophysical instruments after the flood to evaluate scour during the flood.

VII. ORGANIZATION AND OBJECTIVES OF DP-97

ORGANIZATION OF DP-97

- 1.5 days of lecture/workshop
- Optional 1.5 days for field demonstrations
- Fixed instrumentation is also available for installation under this project

I.18 Organization

A. Organization.

1. Primary component of DP-97 is a one and one-half day session where lecture material will be presented and workshop sessions conducted.

2. An optional one and one-half day session using field demonstrations is available. This time could consist of a site visit to a bridge where fixed instrumentation has previously been installed, or a field demonstration of portable, geophysical and/or positioning equipment.

3. Instrumentation is also available under this project. Contact Mr. Tom Krylowski, Federal Highway Administration (202-366-6771) or Mr. Jorge Pagan (202-366-4604) for details.

PARTICIPANT WORKBOOK

- Lesson/workshop schedule provided
- Workbook contains all information to be presented
- Additional notes may be taken

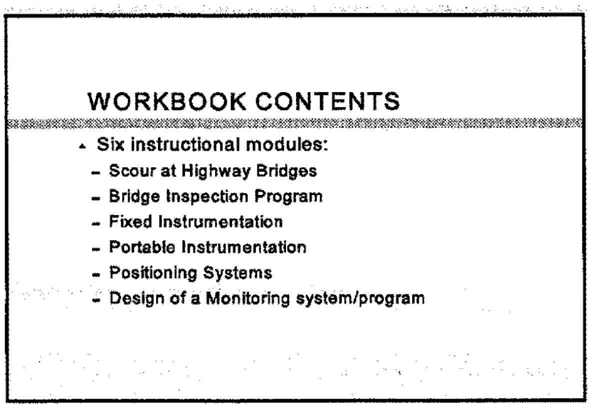
I.19 Workbook

B. Participant Workbook.

1. A schedule has been provided at the beginning of the Participant Workbook. For each lesson, the scheduled time, length, and method of instruction are indicated. Also, a general reference for the material is indicated. More detailed references for each lesson are provided in the Overview section of the cover sheet which introduces each lesson.

2. Workbook contains all information to be presented.

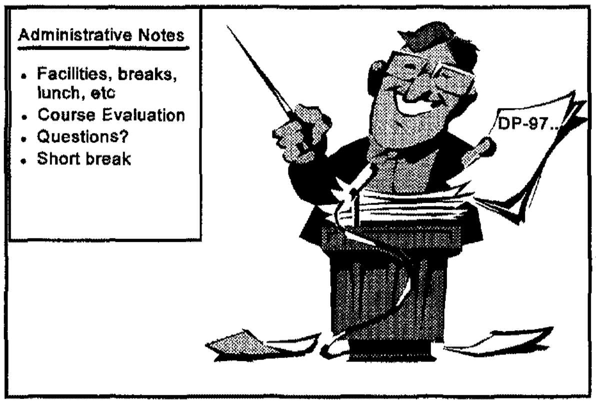
3. Room for additional notes has been provided in the Workbook.



I.20 Workbook content

4. The Workbook includes six instructional modules:

- Scour at Highway Bridges
- Bridge Inspection Program
- Fixed instrumentation
- Portable instrumentation
- Positioning systems
- Design of a monitoring system/program



I.21 Administrative notes

D. Administrative notes.

1. Facilities, breaks, lunch, etc.
2. Course evaluation.
3. Questions?
4. Short break.

LESSON 1

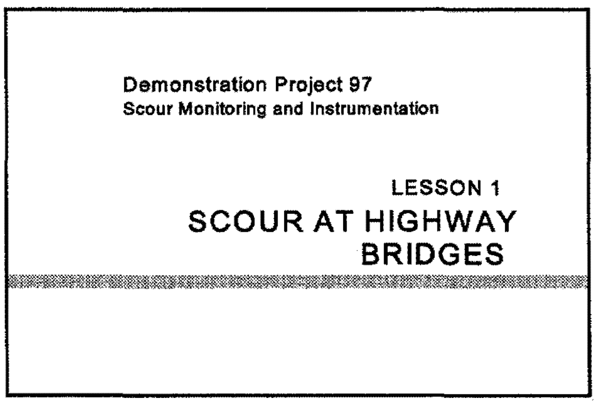
SCOUR AT HIGHWAY BRIDGES

OVERVIEW: Method of Instruction: Lecture

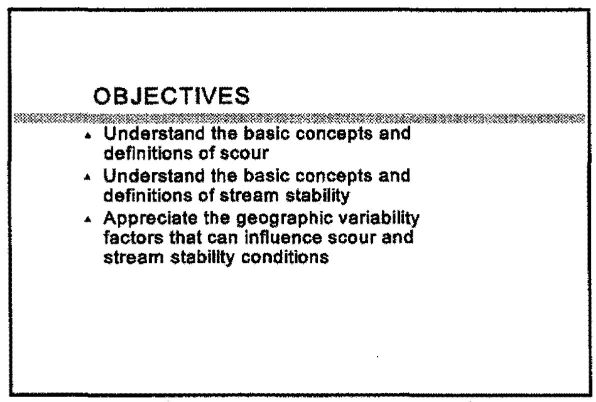
Lesson Length: 60 minutes

Resources:

Lesson Outline
Slides
Video
HEC-18, Chapter 2
HEC-20, Chapter 2



1.0 Title



1.1 Objectives

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

1. **Understand** the basic concepts and definitions of scour.

2. **Understand** the basic concepts and definitions of stream stability.

3. **Appreciate** the geographic variability factors that can influence scour and stream stability conditions.

LESSON 1

SCOUR AT HIGHWAY BRIDGES

I. BASIC CONCEPTS AND DEFINITIONS OF SCOUR

II. BASIC CONCEPTS AND DEFINITIONS OF STREAM STABILITY

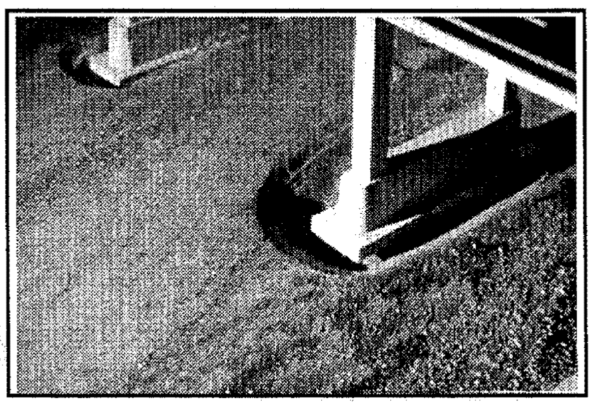
III. GEOGRAPHIC VARIABILITY

LESSON 1

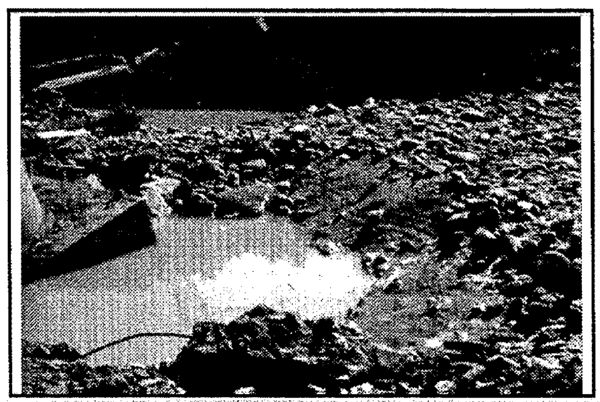
• SCOUR AT HIGHWAY BRIDGES

I. BASIC CONCEPTS AND DEFINITIONS OF SCOUR

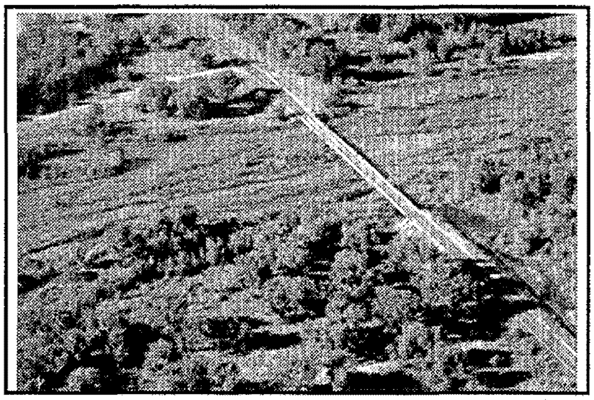
A. Definition of scour. Scour is the result of the erosive action of flowing water, excavating and carrying away material from the bed and banks of streams.



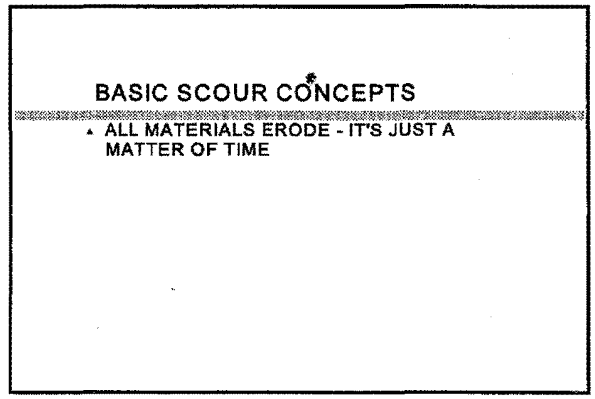
1.2 Schoharie Creek model study scour hole at pier 2 (left) and pier 3 (right)



1.3 Schoharie Creek scour hole at pier 2

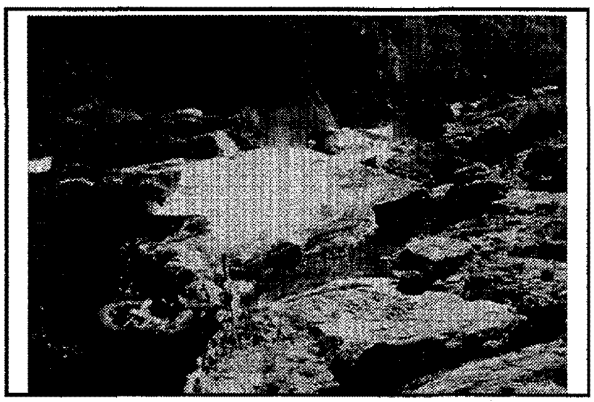


1.4 Abutment scour hole at Goodrich Bridge, Platte River



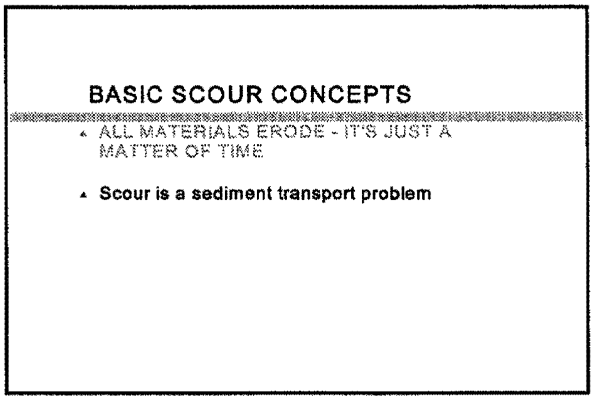
1.5 Scour concepts

B. Basic scour concepts.



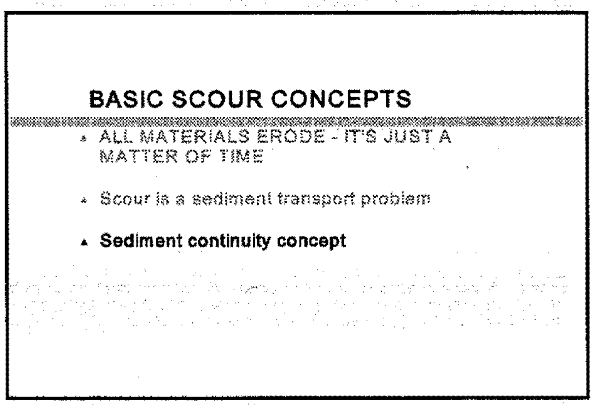
1.6 American River

1. ALL MATERIALS ERODE - IT'S JUST A MATTER OF TIME. 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.

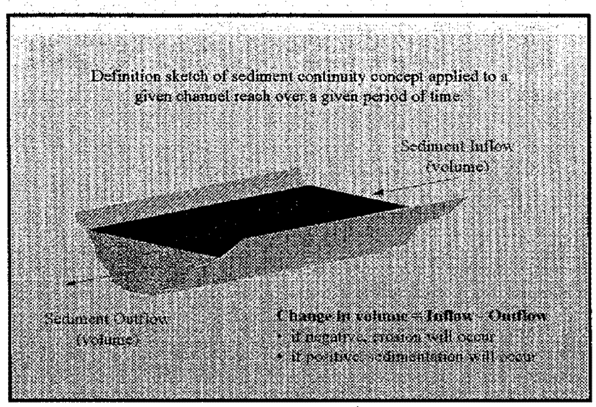


1.7 Scour concepts

2. Scour is a sediment transport problem.



1.8 Scour concepts

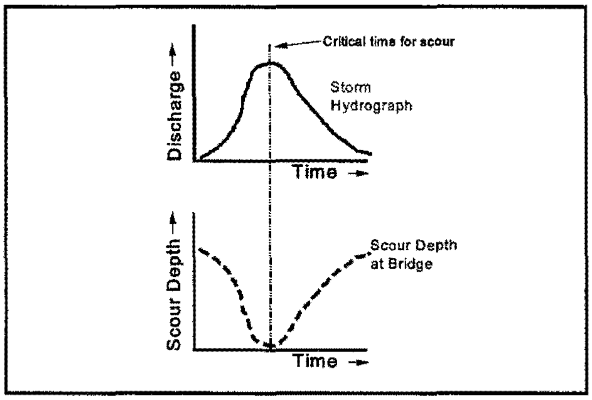


1.9 Sediment continuity sketch

3. Sediment continuity and the control volume concept over a given time step:

   Change in Sediment Volume = Sediment Inflow - Sediment Outflow.

4. Scour occurs when bed material transport, Qs, at bridge crossings, piers or abutments is larger than incoming bed material transport (supply).

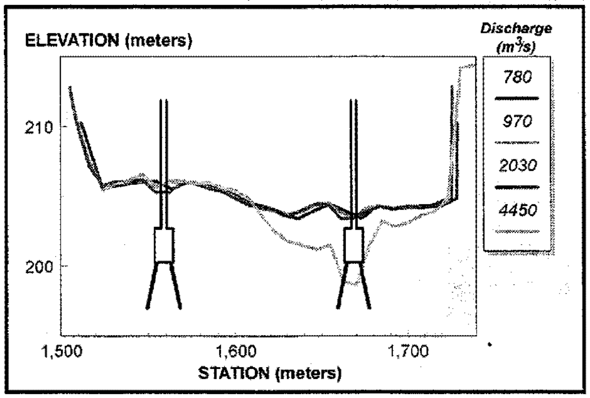


1.10 Temporal change

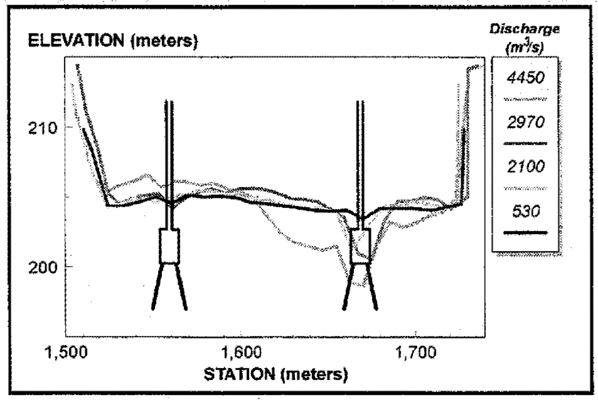
5. Scour generally occurs on rising limb of hydrograph and is a maximum near peak flow. The scour hole can fill on the receding limb of the hydrograph. This phenonemon is illustrated by Slides 1.11 and 1.12:

- Slide 1.11 shows the development of a large scour hole as flow increases from 2,030 m^3/s to 4,450 m^3/s (peak flow).

- Slide 1.12 shows the infilling of that scour hole on the recession, as flow decreases from peak flow conditions.



1.11 Temporal change approaching peak flow



1.12 Temporal change on the recession

CLASSIFYING SCOUR

- Clear-water versus live-bed scour
  - clear-water: bed material is not moving
  - live-bed: bed material is moving
  - floodplain bridges typically clear-water scour; the main channel (particularly at high flow) typically live-bed
- Total scour consists of:
  - local scour
  - contraction scour
  - aggradation/degradation

1.13 Classifying scour

C. Classifying scour:

1. Clear-water versus live-bed scour:

- Live-bed scour occurs when there is bed material transport in the channel upstream of the bridge.

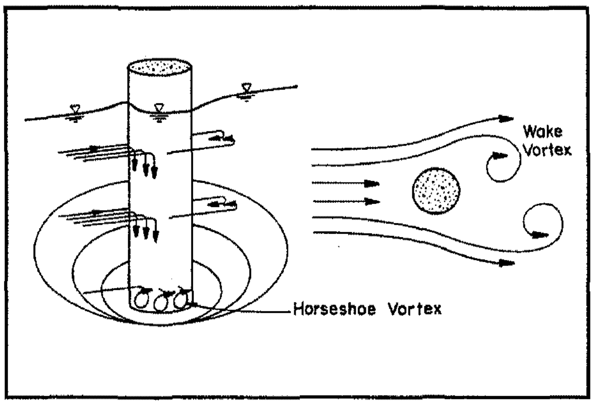
- Clear-water scour occurs when the bed material in the channel upstream of the bridge is not moving (this does not imply fine sediment could not be in motion as wash load).

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

- Relief bridges on the floodplain typically have clear-water scour.

2. Total scour at a highway crossing is comprised of three components: local scour, contraction scour and aggradation/degradation.

D. Local scour involves removal of material from a small portion of the channel width.



1.14 Local scour schematic

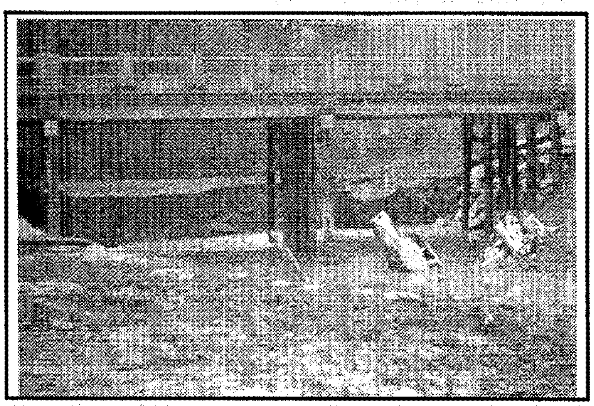
1. Occurs at piers, abutments, spurs, and embankments.

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

3. Local scour can be either live-bed or clear-water.

4. Video of local scour at bridge piers.

E. Contraction scour. Contraction scour involves removal of material from the bed across all or most of the width of the channel and is caused by contraction of flow by bridge or approaches, or a change in downstream control.



1.15 Clear-water contraction scour at a relief bridge

1. Contraction scour can be live-bed or clear-water.

2. Contraction scour can occur in the main channel (generally live-bed), in the overbank (generally clear-water), or both.

3. Clear-water contraction scour at a relief bridge can be quite severe, as illustrated by Slide 1.15.

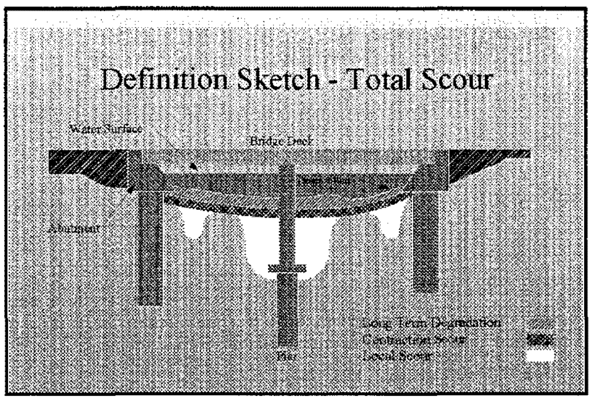
F. Aggradation and degradation are long-term streambed elevation changes occurring over relatively long distances.

1. Aggradation is deposition of material on the streambed.

2. Degradation is lowering or scouring of the streambed.

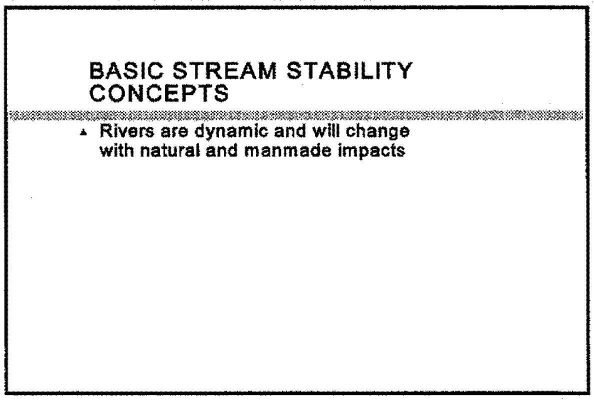
3. Measuring and monitoring aggradation and/or degradation may require data collection away from the bridge.

G. Total scour is the sum of local scour, contraction scour, and aggradation/degradation.



1.16 Total scour definition sketch

II. BASIC CONCEPTS AND DEFINITIONS OF STREAM STABILITY



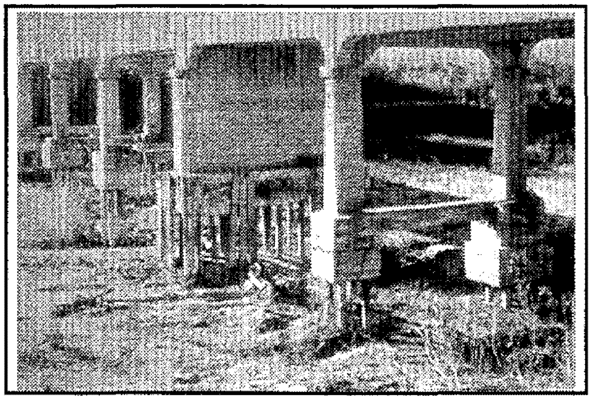
1.17 Stream stability concepts

A. Rivers are dynamic, always changing their position, shape and other morphological characteristics with variation in discharge and the passage of time. These changes occur as a result of both natural and manmade impacts.

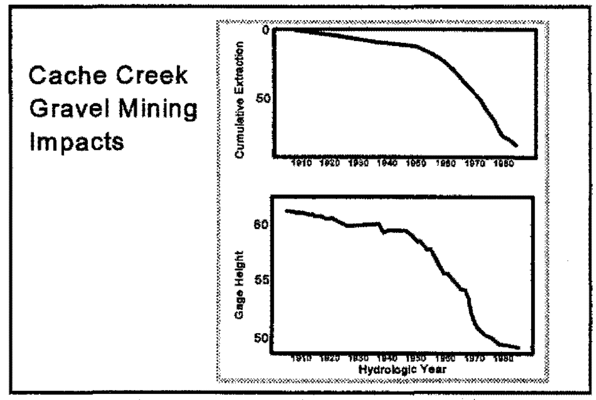
1. Natural impacts include changes in water and sediment supply resulting from fire, earthquakes, landslides, drought, flooding, etc.

2. Manmade impacts include aggregate mining, channel modification, reservoirs, etc.

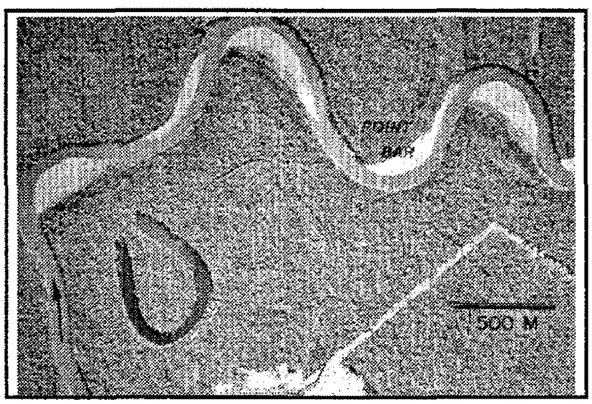
3. When an engineer modifies a channel locally, this local change frequently causes modification of channel characteristics both up- and downstream.



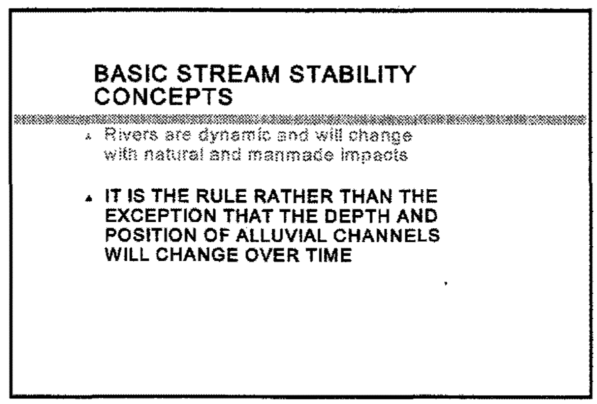
1.18 Degradation at the Cache Creek bridge



1.19 Cache Creek degradation due to aggregate mining



1.20 Lateral instability on the Pearl River



1.21 Stream stability concepts

B. It is the rule rather than the exception that the depth and position of alluvial channels (channels formed in materials that have been and can be transported by water) will change over time.

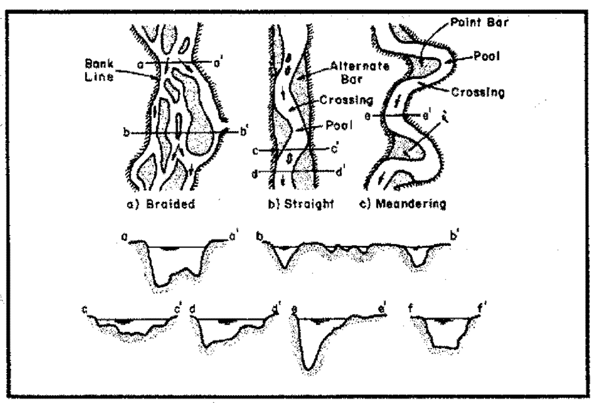
BASIC STREAM STABILITY CONCEPTS

- Rivers are dynamic and will change with natural and manmade impacts
- IT IS THE RULE RATHER THAN THE EXCEPTION THAT THE DEPTH AND POSITION OF ALLUVIAL CHANNELS WILL CHANGE OVER TIME
- **Stream instability may influence placement of scour instrumentation**

1.22 Stream stability concepts

C. Stream instability may influence the placement of fixed scour instrumentation, e.g., the location of greatest scour at a bridge can change with bend migration, or simply from shifting of the thalweg (deepest point in a channel cross section) of the stream within fixed boundaries.

D. Concepts of stream channel planform.



1.23 Channel pattern

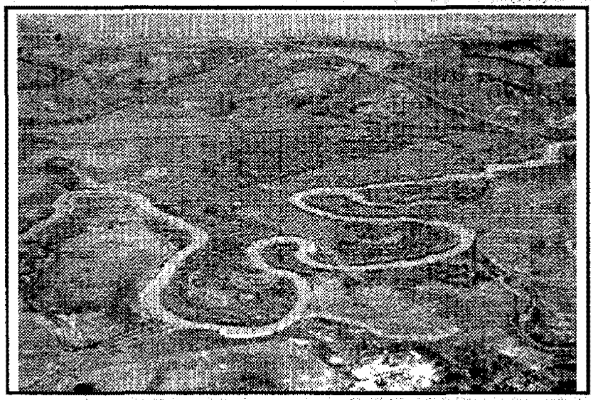
1. Classification of stream channel according to planform (e.g., the shape of the stream when viewed from above) provides insight on stream instability and scour issues.

2. The three basic planform patterns are: braided, straight and meandering.

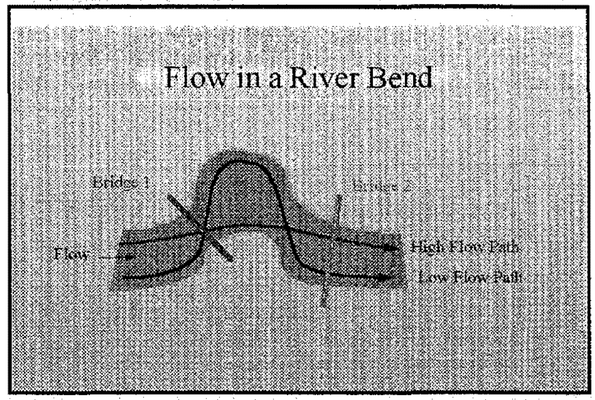
1.24 Platte River braided channel

3. A braided channel consists of multiple and interlacing channels that are unstable and change alignment rapidly. The location of greatest scour at a bridge crossing can shift rapidly during a flood, or from one flood to the next.

4. Straight channels are not common, and even in straight channels the thalweg will meander. As the thalweg shifts the location of maximum scour will change, as will the angle of attack at piers and abutments which further aggravates local scour conditions.



1.25 Beaver Creek, Montana

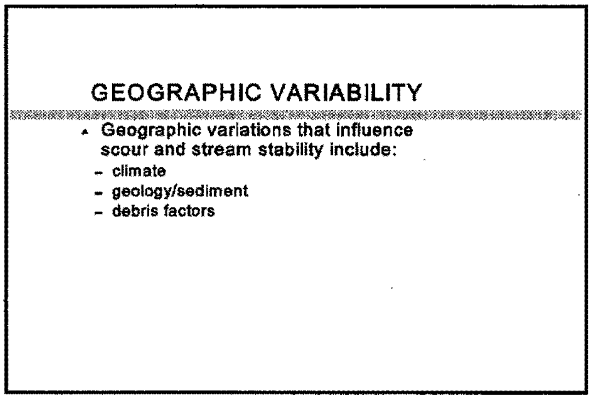


1.26 Flow in a river bend

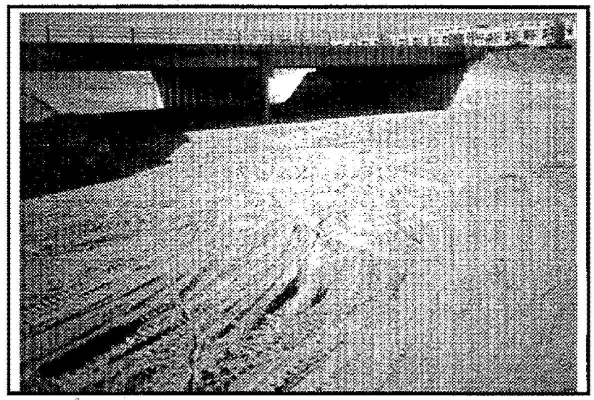
5. Meandering channels can also have shifting thalwegs, with the low-flow thalweg typically being different from the high-flow thalweg. Consequently, the location of maximum scour will change, as will the angle of attack. Furthermore, over time the meander pattern itself can change further impacting scour conditions at a bridge.

NOTES:

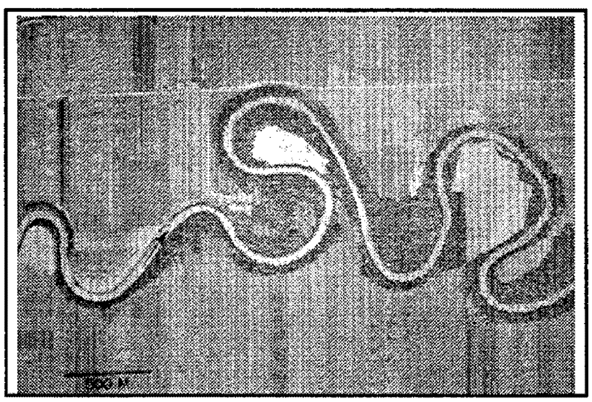
III. GEOGRAPHIC VARIABILITY



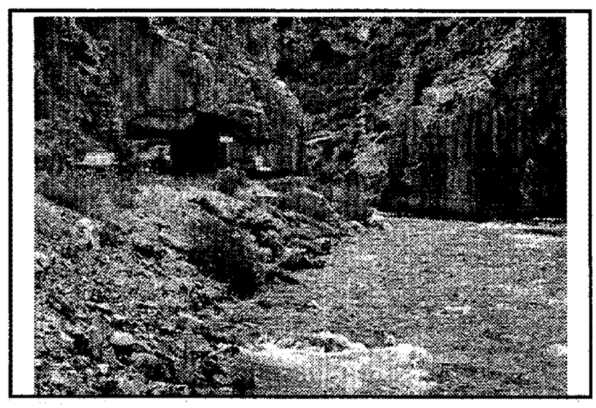
1.27 Geographic variability factors



1.28 Calabacillas Arroyo, New Mexico



1.29 Red Lake River, Minnesota



1.30 Cache la Poudre River, Colorado

A. Geographic variations that influence scour and stream stability conditions include climate, geology/sediment, and debris factors.

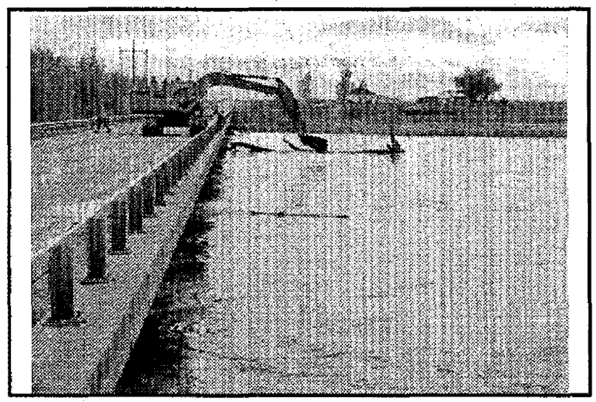
B. In arid regions, stream channel response and the development of serious scour and stream stability problems can occur quickly due to the lack of vegetative cover and the typically erodible soil conditions (Slide 1.28).

C. In humid regions, stream channel response tends to occur more slowly and to develop over longer periods of time. However, streams in humid regions typically have more problems with debris, which can significantly increase local scour conditions at bridge piers (Slide 1.29).

D. Streams in mountainous regions, or areas of high relief, often have fewer scour and stream stability problems due to coarse bed material and/or "nonerodible" bedrock. In contrast, streams in regions of lower relief are usually alluvial and have more problems due to more active channel conditions (Slide 1.30).

E. Debris problems can occur on any river in any geographical region and will create problems in measuring and monitoring scour.

1.31 Debris on the Rio Grande



1.32 Removing debris, South Platte River

LESSON 2

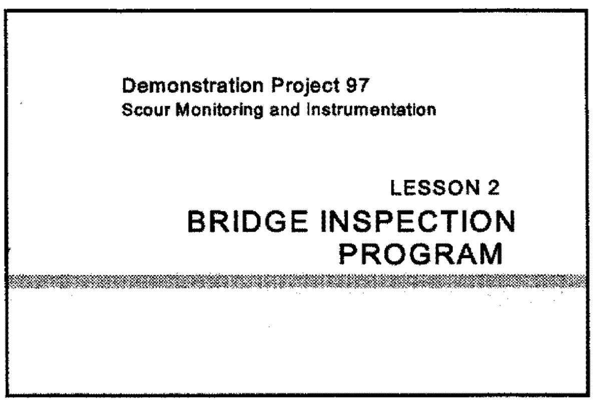
BRIDGE INSPECTION PROGRAM

OVERVIEW: Method of Instruction: Lecture

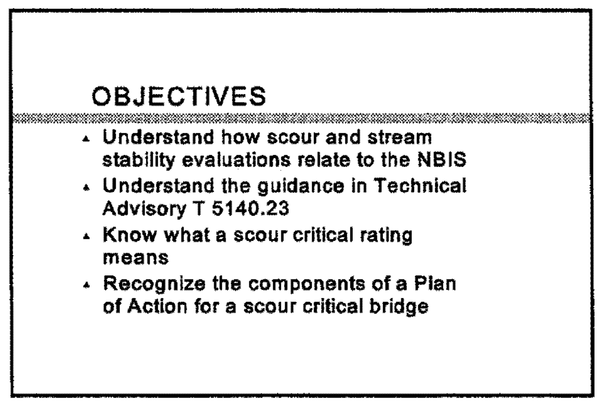
Lesson Length: 45 minutes

Resources:

Lesson Outline
Slides and Video
HEC-18, Chapters 5, 6, and 7
Technical Advisory T 5140.23
1995 Recording and Coding Guide



2.0 Title



2.1 Objectives

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

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

2. **Understand** the guidance in Technical Advisory, T 5140.23, "Evaluating Scour at Bridges," dated October 28, 1991.

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

4. **Recognize** the components of a Plan of Action for a scour critical bridge, in particular, the inspection requirements and the use of monitoring as a countermeasure.

LESSON 2

BRIDGE INSPECTION PROGRAM

I. NBIS REQUIREMENTS RELATED TO UNDERWATER INSPECTION AND SCOUR

II. TECHNICAL ADVISORY T5140.23

III. PLAN OF ACTION

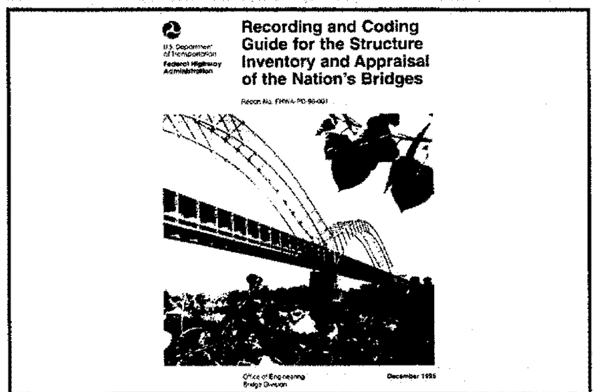
IV. SUMMARY

LESSON 2

BRIDGE INSPECTION PROGRAM

I. NBIS REQUIREMENTS RELATED TO UNDERWATER INSPECTION AND SCOUR

2.2a Bridge inspection crew at work



2.2b Coding Guide

A. Each State Highway Agency shall have a bridge inspection program.

B. Every bridge open to the public shall be inspected at regular intervals not to exceed 2 years. There is a provision for longer periods between inspections if justified and approved.

C. The "Coding Guide" involves nearly 100 separate items describing the bridge, about 25 of which are reviewed at each bridge inspection. Relevant to bridge scour and bed and bank stability the items are:

Item 60, Substructure - describes the physical condition of piers, abutments, piles, fenders, footings or other components

Item 61, Channel and Channel Protection - evaluates physical characteristics such as stream stability, riprap condition, slope protection and stream control structures (including guide banks).

Item 71, Waterway Adequacy - evaluates bridge waterway opening with respect to passage of flow

Items 92 and 93, Critical Feature Inspection - critical features that need special emphasis during inspections; can include need for underwater inspection when scour conditions cannot be determined by other means

Item 113, Scour Critical Bridges - identifies current status of the bridge regarding its vulnerability to scour

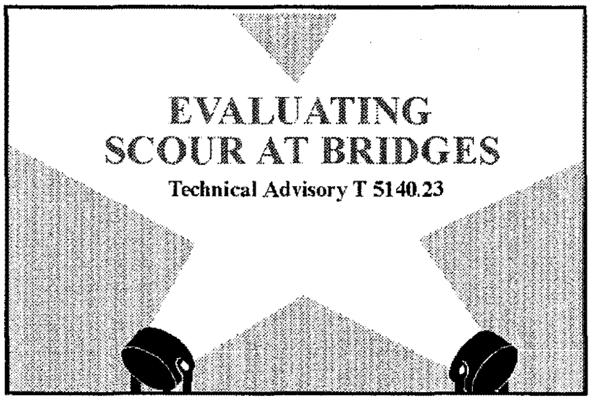
D. The 2-year cycle bridge inspections are the basis for coding Items 60, 61, 71, 92 and 93. Item 113 coding is based on scour evaluations per T 5140.23, Scour at Bridges.

2.3 Dive inspection

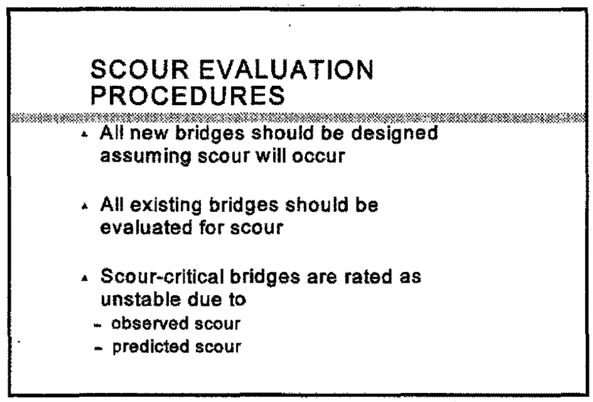
E. Bridges with underwater members which cannot be visually evaluated during periods of low flow or examined by feel for condition, integrity and safe load capacity due to excessive water depth or turbidity shall be inspected by divers at least every 5 years. Divers inspect for both scour and structural 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").

F. Dive inspection for scour monitoring is not always possible, particularly during flood conditions. Furthermore, in large scour holes the diver may not be aware that he/she is encountering scour conditions, eg. A scour hole in Connecticut was 40 m across and 7 m deep; however, visibility was only 0.5-1.0 m and the diver concluded no scour! In this situation, monitoring with appropriate scour instrumentation would be a better approach.

II. TECHNICAL ADVISORY T 5140.23



2.4a Technical Advisory T 5140.23



2.4b Scour evaluations

A. A national scour evaluation process 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, provided guidance on the development and implementation of procedures for evaluating bridge scour.

C. 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. 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. A scour-critical bridge is one with abutment or pier foundations that are rated as unstable due to (1) observed scour at the bridge site, or (2) scour potential as determined from a scour evaluation study.

SCOUR EVALUATIONS

- Results of evaluation coded in Item 113

2.5 Scour evaluations

LOW-RISK BRIDGES

- Code 9 - foundation above flood level
- Code 8 - stable for calculated scour (scour above footing)
- Code 7 - countermeasures installed
- Code 5 - stable for calculated scour (scour within footing or piles)
- Code 4 - stable for calculated scour (field review requires action)

2.6a Low-risk bridges

SCOUR-CRITICAL BRIDGES

- Code 3 - Foundation unstable for calculated scour
- Code 2 - Field review indicates extensive scour has occurred
- Code 1 - Field review indicates that failure is imminent
- Code 0 - Bridge has failed

2.6b Scour-critical bridges

OTHER CODES

- Code 6 - Scour calculation/evaluation has not been made
- Code U - bridge with an unknown foundation that has not been evaluated for scour
- Code T - bridge over tidal waters that has not been evaluated for scour

2.6c Other codes

F. Results of the evaluation are coded in Item 113:

1. Low-risk bridges

   - Code 9. Bridge foundations (including piles) above flood elevation
   - Code 8. Bridge foundations determined to be stable for assessed or calculated scour conditions (scour above top of footing)

- Code 7. Countermeasures have been installed to correct a previously existing problem with scour. Bridge is no longer scour-critical

- Code 5. Bridge foundation determined to be stable for calculated scour; scour within limits of footing or piles

- Code 4. Bridge foundations determined to be stable for calculated scour; field review indicates action is required to protect exposed piles from effects of additional erosion

2. Scour-critical bridges

   - Code 3. Bridge foundations determined to be unstable for calculated scour conditions

   - Code 2. Field review indicates that extensive scour has occurred at bridge foundations

   - Code 1. Field review indicates that failure of piers/abutments is imminent

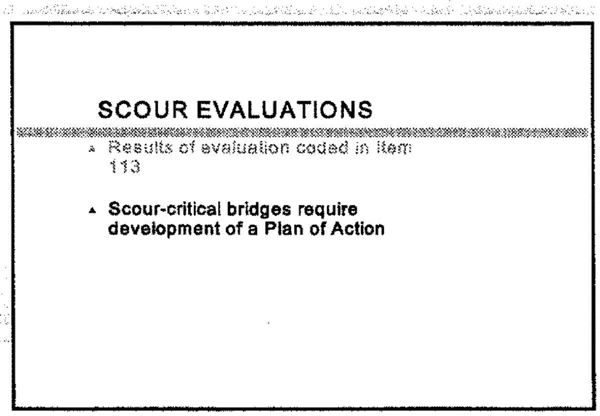
   - Code 0. Bridge has failed

3. Other codes

   - Code 6. Scour calculation/evaluation has not been made (assumes that a bridge has been screened and is scour-susceptible)

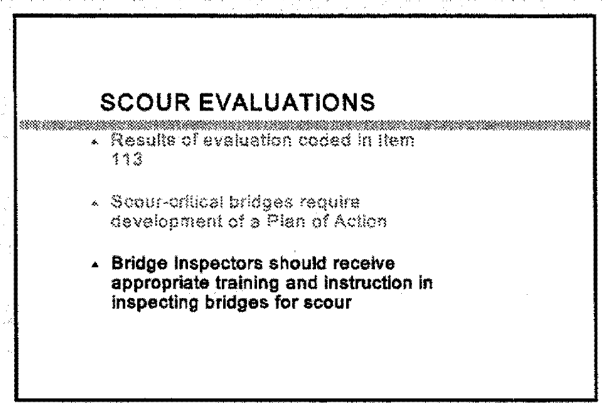
- Code U. Bridge with an "unknown foundation" that has not been evaluated for scour. Since risk cannot be determined, flag for monitoring during flood events, and if appropriate, closure

- Code 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



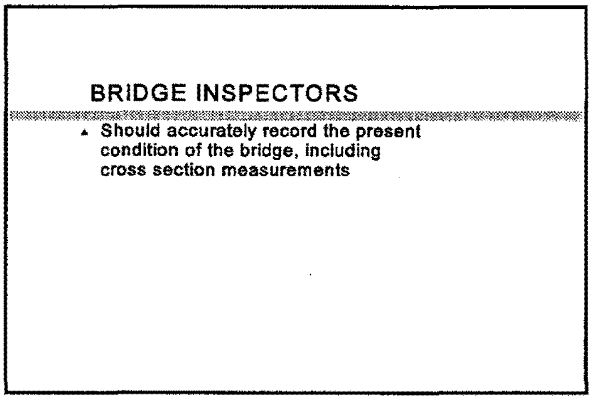
2.7 Scour evaluations

G. Scour-critical bridges require development of a Plan of Action (see below).

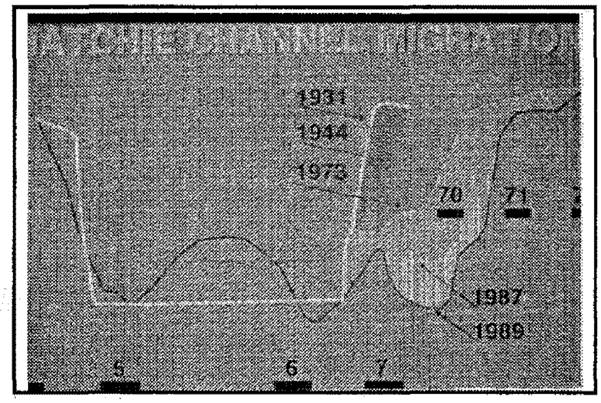


2.8 Scour evaluations

H. Bridge inspectors should receive appropriate training and instruction in inspecting bridges for scour.

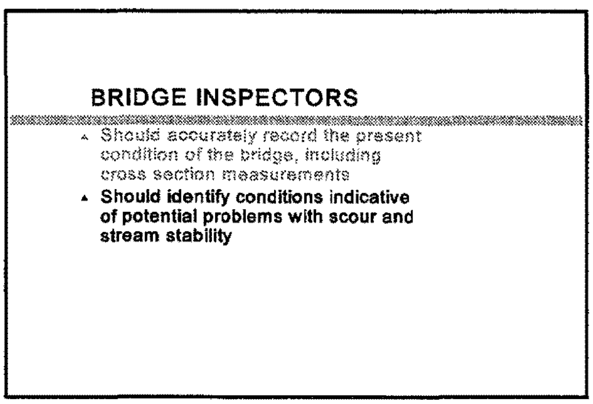


2.9 Bridge inspectors



2.10 Hatchie River cross section changes

1. The bridge inspector should accurately record the present condition of the bridge, including channel cross-section measurements.



2.11a Bridge inspectors

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

BRIDGE INSPECTORS

- Should accurately record the present condition of the bridge, including cross section measurements
- Should identify conditions indicative of potential problems with scour and stream stability
- **Effective notification procedures should be available to permit proper communication of scour findings**

2.11b Bridge inspection

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.

I. If monitoring is used as a scour countermeasure, this needs to be clearly communicated to the bridge inspectors and maintenance personnel. Appropriate data collection and inspections must then be completed before, during and after floods.

III. PLAN OF ACTION

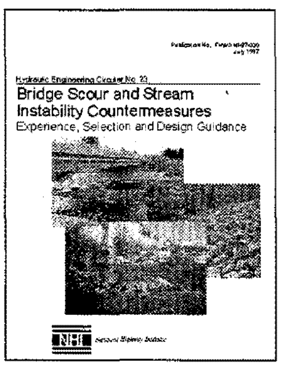
PLAN OF ACTION

- The plan of action describes the countermeasures to be used
- A countermeasure is anything used to monitor, control, inhibit, change, delay or minimize the scour/stream stability problem

2.12 Plan of Action Countermeasures

A. Bridges identified as scour critical, either by office or field review, require development of a Plan of Action.

B. The Plan of Action describes what type of countermeasures will be employed for the identified scour critical condition.



2.13a HEC-23

COUNTERMEASURES

- Hydraulic countermeasures
  - modify the stream flow
  - resist erosive forces
- Structural countermeasures
  - modify bridge substructure
- Monitoring as a countermeasure
  - provides early identification of scour problems allowing for hydraulic/structural countermeasures or bridge closure

2.13b Types of Countermeasures

C. A countermeasure is anything incorporated into the highway-stream crossing to monitor, control, inhibit, change, delay or minimize the stream instability or bridge scour problem. The FHWA publication HEC-23, "Bridge Scour and Stream Instability Countermeasures" provides design guidance for countermeasures often used by State DOT's.

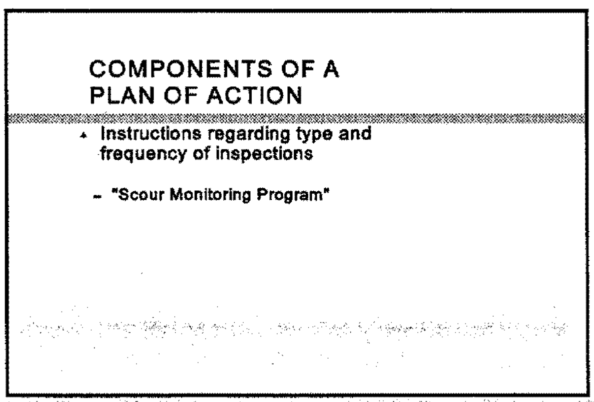
D. The three main groups of countermeasures are:

-*Hydraulic countermeasures* are those primarily designed to modify the stream flow or resist erosive forces. Examples include river training devices and the placement of riprap at piers or abutments.

-*Structural countermeasures* are those that involve modification of the bridge substructure to increase bridge stability. Examples include cross bracing, underpinning and pier modifications.

-*Monitoring* describes activities used to facilitate early identification of potential scour problems, allowing time to implement hydraulic or structural countermeasures and/or to close the bridge.

D. The Plan of Action for scour-critical bridges includes two primary components:



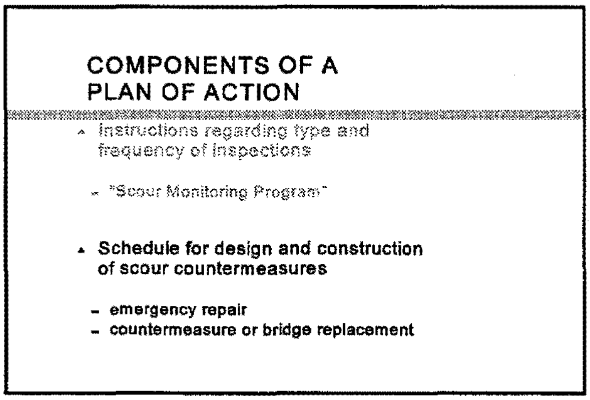
2.14 Plan of action

1. Instructions regarding the type and frequency of inspections to be made at the bridge, particularly in regard to monitoring the performance and closing of the bridge, if necessary.

   The inspection process is facilitated by a "Scour Monitoring Program" that describes both the scour measurements required 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 (remembering the problem of refilled scour holes)
- Continuous scour measurement



2.15 Components of a Plan of Action (cont)

2. A schedule for the timely design and construction of scour countermeasures needed for protection of the bridge.

- The schedule should include any necessary emergency repair work
- The schedule should provide for the timely design and construction of scour countermeasures or immediate bridge replacement depending on risk involved.
- The use of riprap around piers is suggested only as a short term solution for existing bridges. New bridges should not be designed with riprap around the pier foundations. Instead, foundations should be lowered.
- Monitoring may be used in lieu of a hydraulic or structural countermeasure; however, the use of monitoring does not fix the scour problem and the bridge would still be considered scour-critical.

IV. SUMMARY

A. A short video, "Scour at Bridge Piers," will be shown that summarizes many of the important concepts from Lessons 1 and 2.

B. The video reviews scour and stream stability concepts, the types of scour, reference materials available (HEC-18 and HEC-20), scour critical bridges and item 113 coding, etc.

NOTES:

LESSON 3

FIXED INSTRUMENTATION

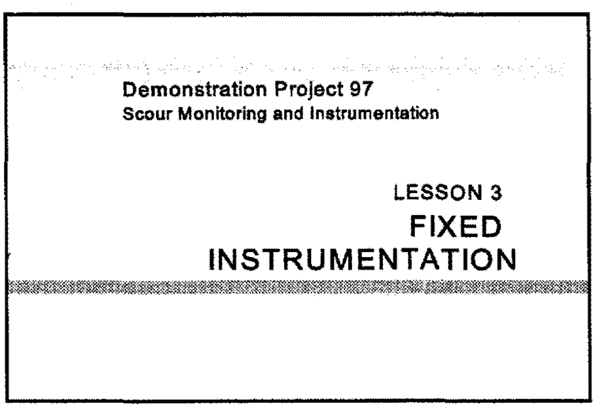
OVERVIEW:

Method of Instruction: Lecture and Demonstration

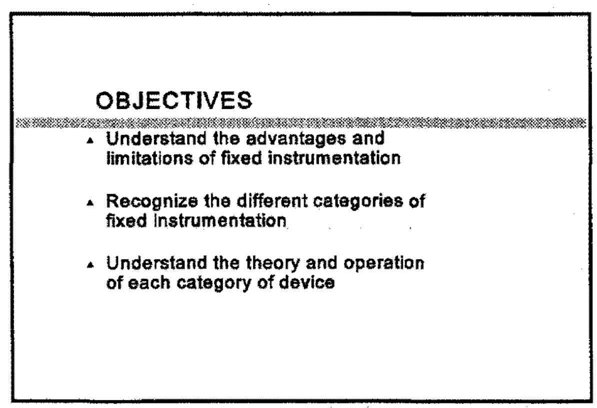
Lesson Length: 60 minutes Lecture
90 minutes Demonstration

Resources:

Lesson Outline
Slides
Demonstration Equipment



3.0 Title



3.1 Objectives

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

1. **Understand** the advantages and limitations of fixed instrumentation.

2. **Recognize** the different categories of fixed instrumentation.

3. **Understand** the theory and operation of each category of device.

LESSON 3

FIXED INSTRUMENTATION

PART 1 - LECTURE

I. NEED, ADVANTAGES AND LIMITATIONS OF FIXED INSTRUMENTATION

II. CATEGORIES OF FIXED INSTRUMENTATION

III. SONAR

IV. SOUNDING RODS

V. BURIED/DRIVEN RODS

VI. OTHER BURIED DEVICES

PART 2 - DEMONSTRATION

I. SONAR

II. SOUNDING RODS

III. BURIED/DRIVEN RODS

IV. OTHER BURIED DEVICES

LESSON 3

FIXED INSTRUMENTATION

PART 1 - LECTURE

I. NEED, ADVANTAGES, AND LIMITATIONS OF FIXED INSTRUMENTATION

NEED FOR FIXED INSTRUMENTATION

- Definition

  Fixed instrumentation is instrumentation installed and left at the bridge

- Fixed instrumentation is used when frequent measurements and/or regular monitoring are required

3.2 Need

A. Need for fixed instrumentation.

1. Fixed instrumentation is instrumentation that is installed and left at the bridge.

2. Fixed instrumentation is used when frequent measurements and/or regular monitoring (e.g., weekly, daily or continuous) are required.

FIXED INSTRUMENTATION Advantages

- Continuous monitoring
- Low operational cost
- Little special training required
- Easy to use and get data

3.3 Advantages

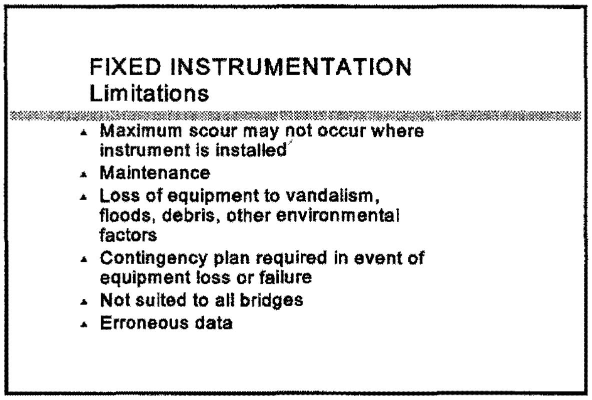
B. Advantages of fixed instrumentation.

1. Continuous monitoring possible at a given site.

2. Once installed has low operational cost.

3. Extensive specialized training typically not required.

4. Easy to use and get data.



3.4 Limitations

C. Limitations of fixed instrumentation.

1. The maximum scour may not occur at the location where the instrument is installed, as a result of changes in scour or stream stability conditions, including:

skew angle
debris/ice accumulation
shifting thalweg conditions
sand bar deposition
lateral migration
bank instability

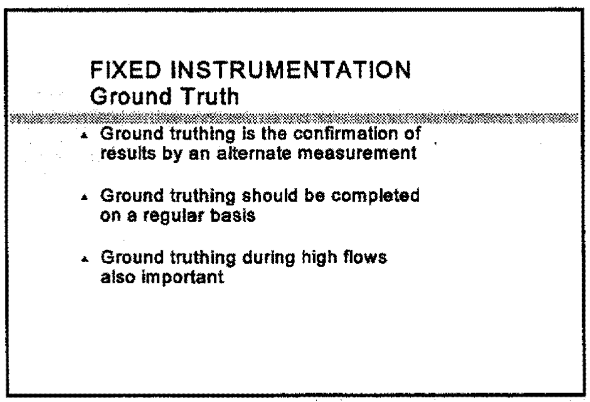
2. Maintenance of equipment exposed to adverse environmental factors.

3. Loss of equipment due to vandalism, floods, debris, and other environmental factors.

4. May need a contingency plan to ensure data are available in the event of equipment failure or loss, particularly during a severe flood.

5. Not all bridges are suitable for fixed instrumentation.

6. Erroneous data from instrument (i.e., reading off debris instead of channel bottom).



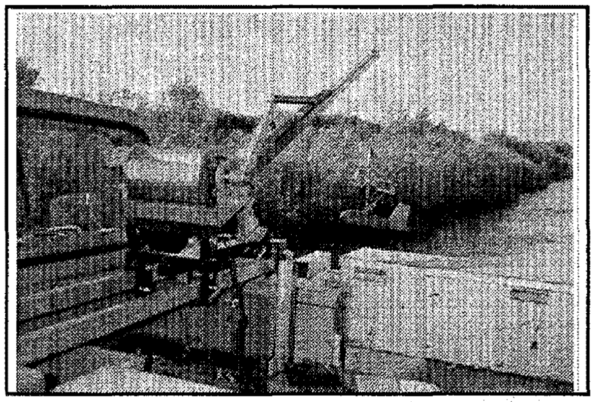
3.5 Ground truth

D. Ground truth requirements.

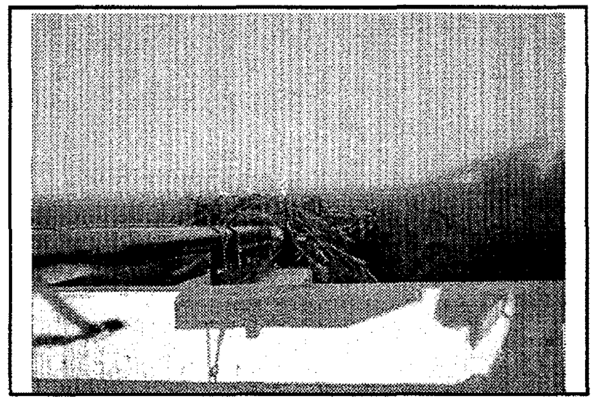
1. Ground truthing is the confirmation of instrument results by some form of observation or alternate measurement technique.

2. Ground truthing should be completed on a regular basis to verify the accuracy of fixed instrumentation results.

3. Ground truthing should also be completed at high flows, but this can be difficult.

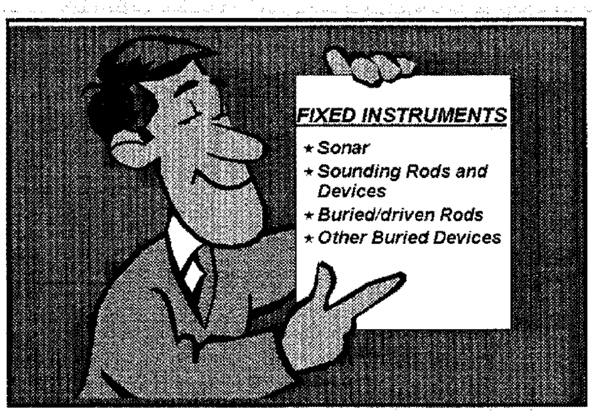


3.6a Steam gaging equipment used in ground truthing



3.6b Debris pile on sonar instrument in New Mexico

II. CATEGORIES OF FIXED INSTRUMENTATION



3.7 Categories of devices

A. Sonar (Electronic Echo Sounders) based devices.

   1. Low-cost fish-finder type sonar devices.

   2. Other sonar devices.

B. Sounding rods/devices.

   1. Manually operated.

   2. Automatically operated.

C. Buried/driven rods.

1. Mechanical devices (e.g,. sliding collar instruments).

2. Electrical devices (e.g., conductance probes).

3. Electromechanical devices (e.g., piezoelectric film devices).

D. Other buried devices.

1. Tethered sensors.

2. Untethered sensors.

3. Other devices.

III. SONAR

SONAR
Theory and Operation

- "Fish-finders" versus other sonar devices
- Instrument shelter, transducer mounting and data logging/telemetry
- Measurement based on velocity of sound

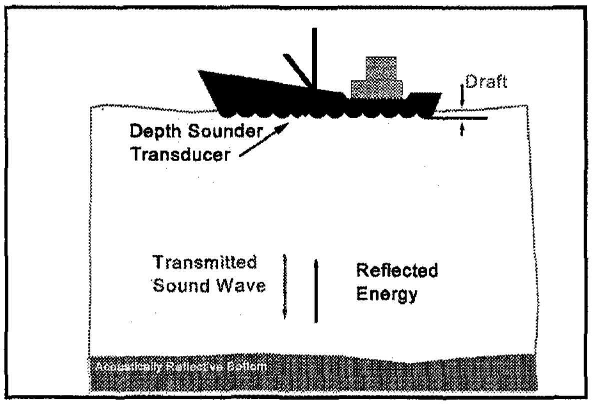
3.8 Sonar theory and operation

A. Theory and operation.

1. Sonar units, also called electronic echo sounders or black and white fathometers, are typically simple to operate. The use of sonar in recreational boating and fishing is well established and a number of companies manufacture devices marketed to boaters (fish-finder type devices). Other sonar instruments are also available that provide greater accuracy, multiple transducer operation and other enhancements.

2. The operation of sonar as a fixed instrument typically has the instrument mounted in an instrument shelter and the transducer mounted on a bridge pier. Data logging or telemetry are available.

3. Sonar measurement is based on the elapsed time that an acoustic pulse takes to travel from a generating transducer to the waterway bottom and back. If the velocity of sound propagation in the water column is known, the travel time of the reflected wave can be converted into distance. This is expressed by the following general formula:



3.9 Schematic of echo sounding

DEPTH FORMULA

depth = (velocity x travel time) / 2

+ system index constant

+ draft

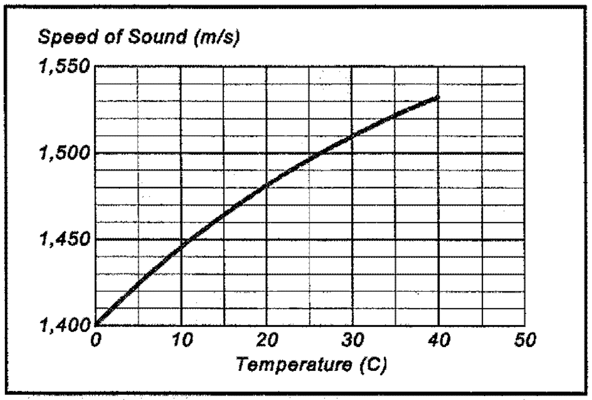
3.10 Depth formula

$$d = (v \cdot t) / 2 + k + d_r$$

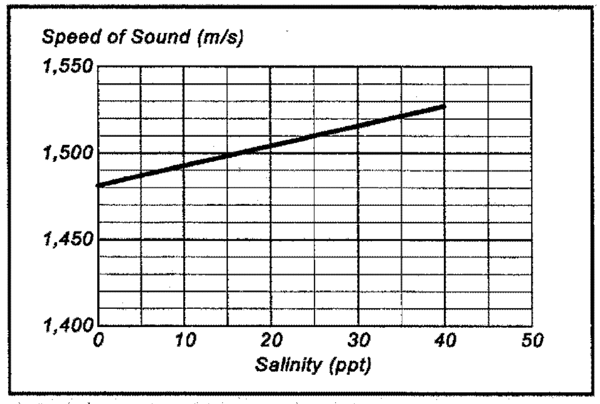
where

- d = Depth from reference water surface
- v = Average velocity of sound in the water column
- t = Measured elapsed time from transducer to bottom and back to transducer
- k = System index constant
- d_r = Distance from reference water surface to transducer (draft)

The parameters v, t, and d_r cannot be perfectly determined during the echo sounding process, and k must be determined from periodic calibration of the equipment. t is also dependent on the reflectivity of the bottom. The shape or sharpness of the returning pulse plays a major role in the accuracy and detection capabilities of depth measurement.



3.11 Speed of sound vs. temperature



3.12 Speed of sound vs. salinity

4. In water, the velocity of sound varies with the density of the medium. The density is primarily a function of the water temperature and suspended or dissolved solids content, i.e., salinity.

Velocity can range from 1,400 to 1,500 m/s. Since many project sites can exhibit large variations in temperature and/or salinity with depth, the velocity of the projected sound wave will not be constant over the distance. The effect of this variation can be significant. For example, a temperature change of 10°C will change the velocity by as much as 40 m/s, causing a potential error of about 0.15 m in a 5 m depth reading. Similarly, at a temperature of 15°C, a 10-parts per thousand (ppt) salinity change will change the velocity by about 10 m/s, resulting in a potential error of 0.07 m in 5 m. For practical echo sounding work, an average velocity of sound is usually assumed (by calibration), since the process of measuring and correcting for actual variations at each depth interval is difficult.

SONAR
Theory and Operation

- *"Fish-finders" versus other sonar devices*
- *Instrument shelter, transducer mounting and data logging/telemetry*
- *Measurement based on velocity of sound*
- ***Calibration requirements***

3.13 Calibration

5. The travel time of the sound pulse is measured either electronically in a depth digitizing device or mechanically (graphically) on an analog recording type instrument. The accuracy of the absolute time measurement generally varies with depth due to signal attenuation and noise.

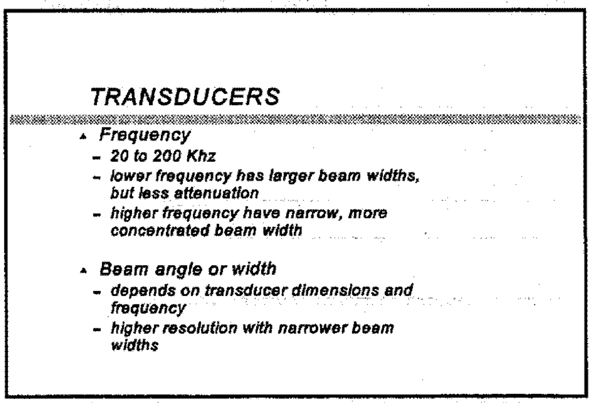
   The acoustic reflectivity characteristics of the target, i.e., size, shape, orientation, material, etc., can significantly impact the returning pulse. Variations in return signal strength and sharpness will affect the depth measurement accuracy.

   The nominal accuracy of echo sounding time (of wave travel) measurement is usually rated by manufacturers at ±3 cm plus 0.1 to 0.5 percent of the depth, or a precision range of ±5 cm to ±10 cm in 15 m and is independent of the acoustic reflection characteristics.

6. The transducer draft must be applied to the measured time distance to obtain the corrected depth from the reference water surface. Also, any electrical and/or mechanical delays inherent in the measuring system, including return signal threshold detection variations must be accounted for. The only effective method of determining the correct depth is by a bar check calibration, which is the process of suspending a metal bar or other target a known distance below the transducer to verify echo sounder accuracy.

7. Measurements around bridges can result in interference from piers, footings, etc. that create secondary signal returns (side lobes) that need to be discriminated from the primary sound wave (main lobe).

B. Transducers.



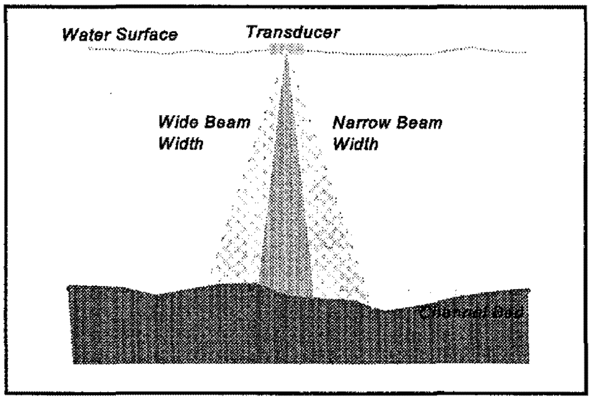
3.14 Transducers

A transducer converts electronic energy to acoustical pulses and vice versa. The type of transducer used is a major determining factor in the accuracy and adequacy of a depth measurement.

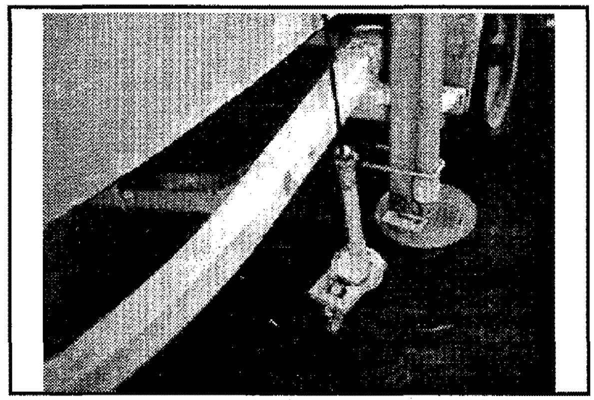
1. Transducer frequency - Transducers for echo sounders have frequencies between 20 and 200 Khz. The standard frequency for echo sounding is 200 Khz ±10 percent for single-frequency systems.

   Low frequency transducers have large beam widths, which tends to smooth bottom features, but have less attenuation allowing deeper measurements.

   High frequency transducers have narrow, more concentrated beam widths allowing more accurate detailing of bottom features, but the high signal attenuation limits depth and ability to operate in high suspended sediments.

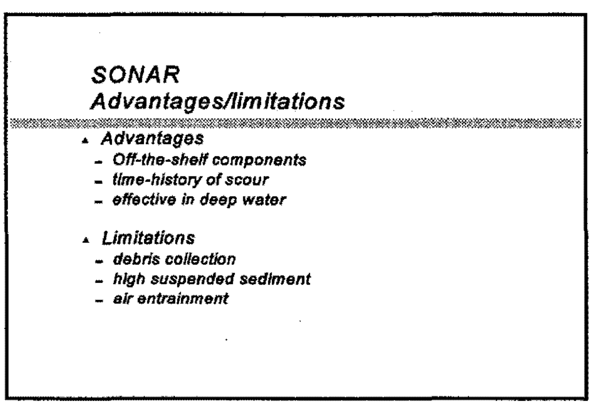


3.15 Transducer beam angle



3.16 Wide and narrow beam transducer

2. Transducer beam angle - The angle, or width, of the radiated acoustical beam is a function of the transducer dimensions and frequency. The highest level of resolution is obtained by the narrowest beam width.



3.17 Advantages/limitations

C. Advantages and limitations.

Advantages:

- Fixed sonar instrument can be assembled from off-the-shelf components
- Provides a time-history of scour
- Can be used in deep water situations

Limitations:

- Debris collection is a problem
- High sediment and/or air entrainment can be problems

SONAR
Equipment Sources

- *"Fish finder" type devices readily available from boat/marine sources*
- *Other sonar devices. Odom, Innerspace, Ross, etc.*
- *Complete systems. ETI Instruments, Inc., Datasonics*

3.18 Equipment sources

D. Equipment sources.

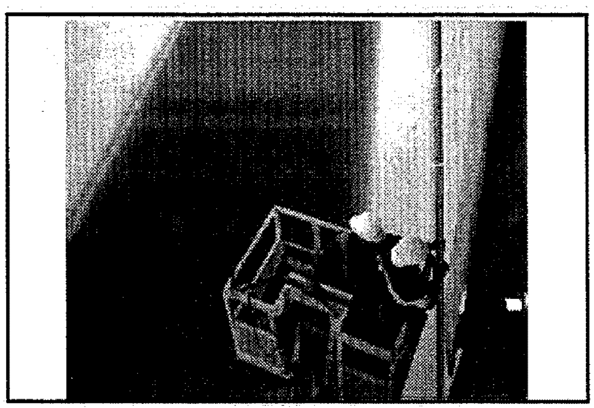
1. "Fish-finder" type devices - see any boating/marine products catalog or boat/marine store [e.g., West Marine (800-538-0775), Bass Pro Shops (800-227-7776), and Cabela's (800-237-4444)]. Strip chart or paper readout is useful and valuable for documentation.

2. Other sonar devices - Odom Hydrographic Systems, Inc., Baton Rouge, Louisiana (504-769-3051); Innerspace Technology, Inc., Waldwick, New Jersey (201-447-0398); Ross Laboratories, Inc., Seattle, Washington (206-324-3950), etc.

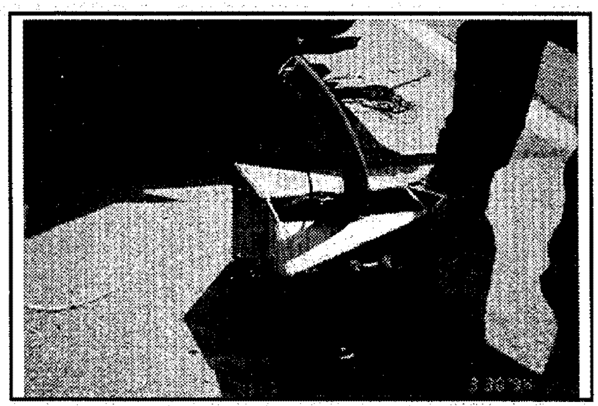
3. Complete fixed sonar instrument systems - ETI Instruments, Inc., Fort Collins, Colorado (970-484-9393); Datasonics, Inc., Mineola, New York (508-563-5511).

E. Case histories.

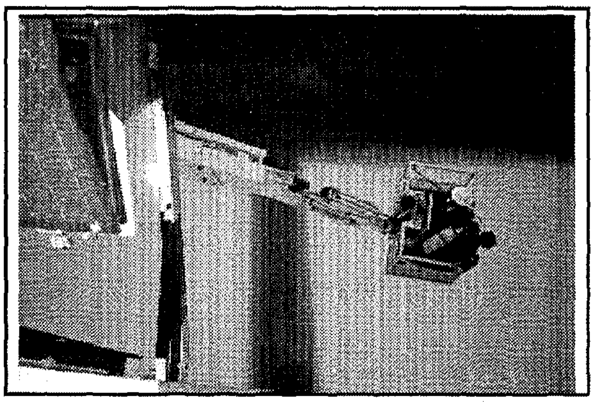
1. U.S. 59 Bridge over Trinity River, Texas.
2. Johns Pass bridge near St. Petersburg, Florida.
3. San Antonio Bridge over Rio Grande River, New Mexico.
4. Hood River, Oregon.



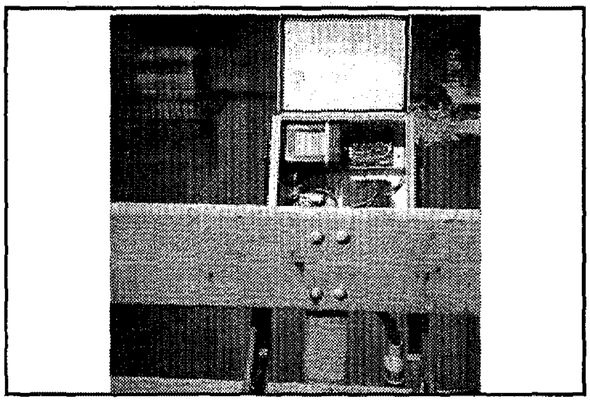
3.19 Installing conduit, Trinity River



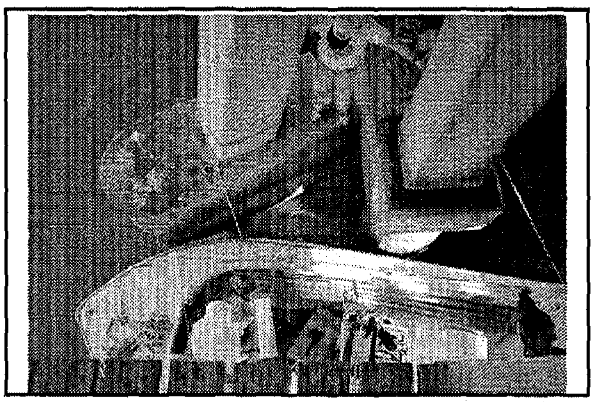
3.20 Transducer housing, Trinity River



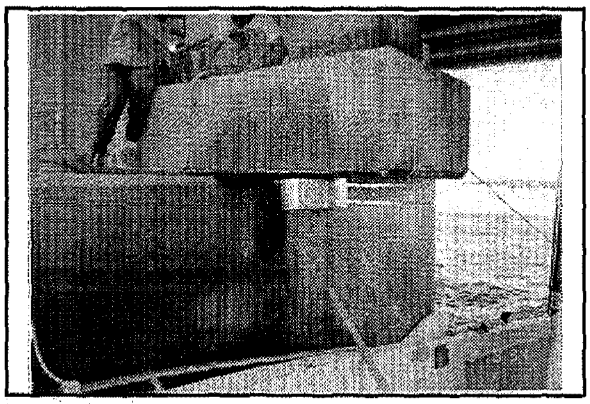
3.21 Diver installation, Trinity River



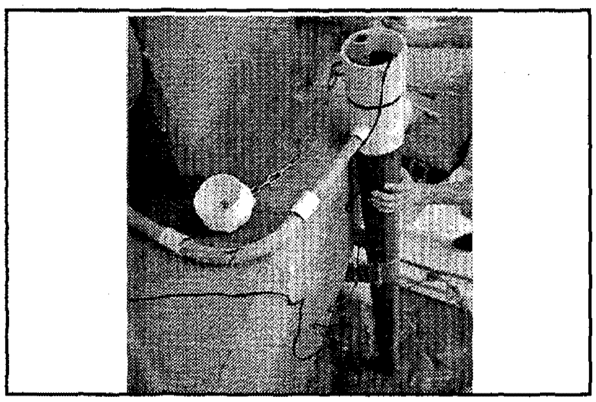
3.22 Instrument shelter, Trinity River



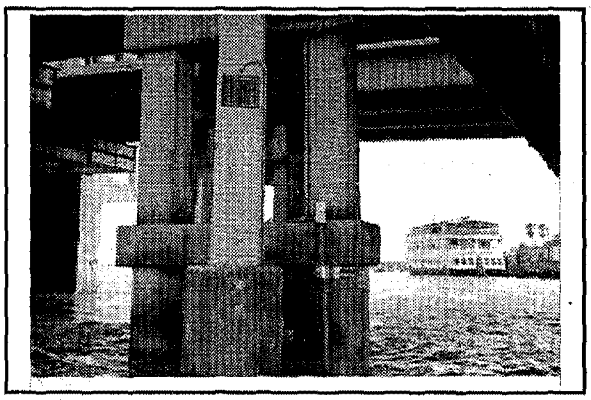
3.23 Johns Pass crutch pile



3.24 Transducer mounting bracket, Johns Pass



3.25 Transducer housing, Johns Pass



3.26 Completed installation

IV. SOUNDING RODS

SOUNDING RODS
Theory and Operation

- *Sliding rod with a foot pad resting on bed*
- *Manual or automatic operation*
- *Automatic operation requires linear displacement measurement*

3.35 Sounding rods

A. Theory and operation.

1. Sounding rods in a fixed instrument application typically involve a sliding rod fastened to the bridge with a foot pad resting on the bed. As a scour hole develops the rod drops downward.

2. Sounding rods can be either manually or automatically operated. Manually, the displacement of the rod from a previous reading is noted. The rod may be left sitting on the bed between measurements, or may be raised out of the water.

3. An automatic sounding rod requires a linear displacement measuring device to track the rod location, which may or may not then be recorded by a data logger and/or transferred by telemetry to another location.

SOUNDING RODS
Advantages/Limitations

- *Advantages*
  - ***Relatively simple, mechanical instrument***
  - ***well-suited for channels with coarse bed material***
- *Limitations*
  - ***unsupported length concerns***
  - ***vibration and vortex shedding***
  - ***binding***
  - ***augering into fine sediments***

3.36 Advantages/limitations

B. Advantages and limitations.

Advantages:

- Relatively simple mechanical instrument
- Well suited for coarse channels

Limitations:

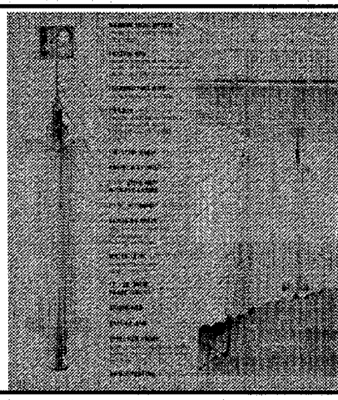
- Maximum extension limited by unsupported length
- Vibration from vortex shedding can be a problem
- Binding with sediment can be a problem
- Can auger into fine sediment channels

SOUNDING RODS
Equipment Sources

- ***Brisco monitor***

3.37 Sounding rods

C. Equipment sources.

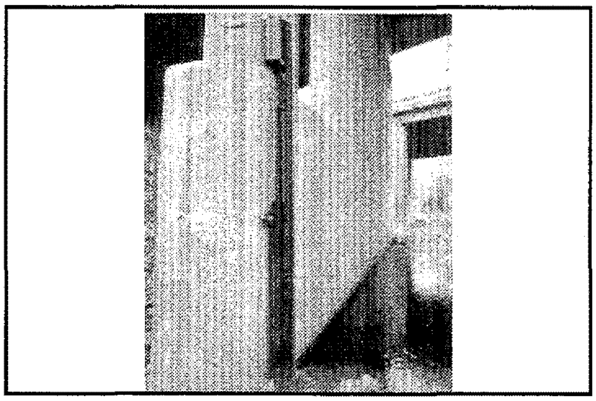


3.38 Brisco Monitor schematic

1. Brisco Monitor, Cayuga Industries, Inc., Schenectady, New York (518-372-8627).

D. Case histories.

1. Vertically supported sounding rods have been used in depth sounding for decades, and for measuring scour at bridge piers since at least 1921.



3.39 Brisco Monitor New York

2. Brisco Monitor installations in New York.

V. BURIED/DRIVEN RODS

BURIED/DRIVEN RODS
Theory and Operation

- *This class includes all sensors and instruments supported by a vertical member driven or placed vertically in the bed*
- *Scour measurement by mechanical, electrical, or electromechanical sensors*

3.40 Buried/driven rods

A. This class of measuring device includes all sensors and instruments supported by a vertical member such as a pipe, rail, or column which could be driven or placed vertically in the bed at the location where scour would be expected to occur. Scour measurement along the buried/driven rod can be by mechanical, electrical, or electromechanical sensors.

MECHANICAL SENSORS
Theory and Operation

- *Sliding collar placed around the buried/driven rod*
- *Collar location detected by magnetic tracing*

3.41 Theory and operation

B. Mechanical sensors.

1. Theory and operation - Scour measurement by mechanical detection is typically based on a sliding collar placed around the buried/driven rod that can move freely downward as scour progresses. The location of the collar has been determined successfully using magnetic tracing.

MECHANICAL SENSORS
Advantages/limitations

- *Advantages*
  - *Relatively simple mechanical device*
  - *Relatively low cost*
- *Limitations*
  - *Installation can be a problem in coarse material or with debris*
  - *Collar subject to binding*
  - *Unsupported length and vibration*

3.42 Advantages/limitations

2. Advantages and limitations.

Advantages:

- Relatively simple, mechanical device
- Relatively low cost

Limitations:

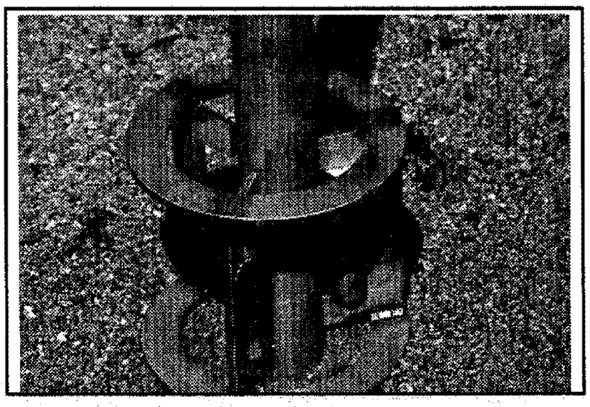
- Installation in coarse bed channels can be a problem
- Collar subject binding or jamming by debris
- Unsupported length and vibration can be a problem

MECHANICAL SENSORS
Equipment Sources

- *Sliding collar device developed under NCHRP Project 21-3*

3.43 Equipment sources

3. Equipment sources.



3.44 NCHRP 21-3 Sliding Collar device

A magnetic sliding collar device was developed under the NCHRP Research Project 21-3. This device is available as a manual readout or as an automated readout with a data logger. The Phase III report for Project 21-3 contains plans and specifications for building a magnetic sliding collar device. Ready-to-install magnetic sliding collar devices are available from ETI Instrument Systems, Inc., Fort Collins, Colorado (970-484-9393).

ELECTRICAL SENSORS
Theory and Operation

- ***Typically based on conductance***
- ***Measurement based on differences in conductivity between water and sediment***

3.45 Electrical sensors

C. Electrical sensors.

1. Theory and operation - Scour measurement by electrical detection has been based primarily on conductance. Sensors are placed along the buried/driven rod at a prescribed interval and the conductivity is measured between each pair of electrodes. The soil-water interface is detected by comparing conductivity reading along the buried/driven rod, with the conductivity of water being higher than the conductivity of soil.

ELECTRICAL SENSORS
Advantages/limitations

- *Advantages*
  - *Not directly affected by debris*
- *Limitations*
  - *problems discriminating changes in conductivity*
  - *sensor damage during installation*
  - *sensor damage by ice/debris impact*

3.46 Advantages/limitations

2. Advantages and limitations.

Advantages:

- Not directly affected by debris

Limitations:

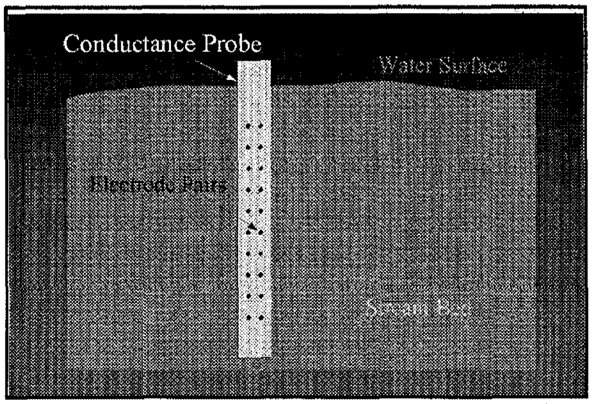
- Problems discriminating changes in conductivity
- Sensor damage during installation
- Sensor damage by ice/debris impact

ELECTRICAL SENSORS
Equipment Sources

- *Mostly experimental, including recent work by USGS*

3.47 Equipment sources

3. Equipment sources.



3.48 Conductance probe

The USGS has built a conductance probe that was tested in Arkansas with limited success. Problems occurred with the data logger and in detecting the soil-water interface in sediment-laden flows (Courtney 1986).

ELECTROMECHANICAL
Theory and Operation

- *Electromechanical sensors placed along buried/driven rod*
- *Sensors include tip switches and piezofilm devices*

3.49 Theory and operation

D. Electromechanical detection devices.

1. Theory and operation - Scour measurement by electromechanical detection can be based on several techniques. Sensors are again placed along the buried/driven rod at prescribed intervals and the extent of scour determined by sensor readings. Sensors include devices as simple as mercury tip switches to sophisticated piezoelectric film devices (a piezoelectric device generates a small current when vibrated).

ELECTROMECHANCIAL
Advantages/limitations

- ***Advantages***
  - ***Relatively simple in concept***
  - ***Relatively low cost***
  - ***Not directly affected by debris***
- ***Limitations***
  - ***Installation can be a problem in coarse material or with debris***
  - ***Unsupported length and vibration***
  - ***sensor damage during installation***
  - ***sensor damage by ice/debris impact***

3.50 Advantages/limitations

2. Advantages and limitations.

Advantages:

- Relatively simple in concept
- Relatively low cost
- Not directly affected by debris

Limitations:

- Installation can be difficult in coarse bed channels
- Unsupported length and vibration can be a problem
- Sensor damage during installation
- Sensor damage by ice\debris impact

ELECTROMECHANICAL
Equipment Sources

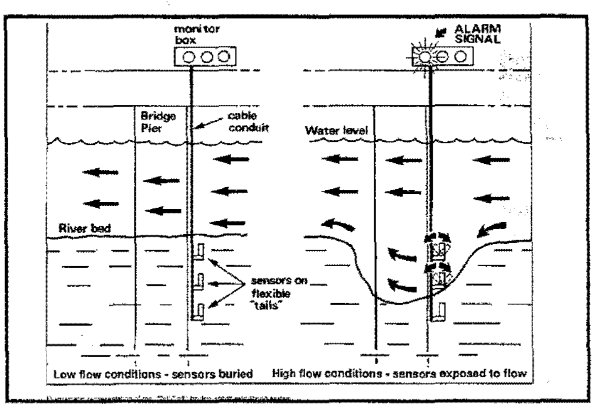
- *"Tell-Tail" device developed by Hydraulics Research, UK*
- *Piezoelectric device developed under NCHRP 21-3*

3.51 Equipment sources

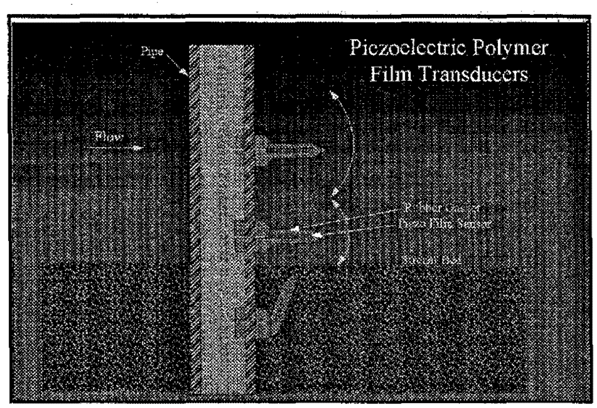
3. Equipment sources.

A buried/driven rod device was developed by Hydraulics Research Limited, Wallingford, UK. The device is called the "Tell-Tail" bridge scour monitoring system, and as of 1990 was subject to a patent application. The sensors are mercury tip switches enclosed in the end of a flexible rubber tube. The switches are connected to a monitor that records the time that the switch is activated.

A piezoelectric device was investigated under the NCHRP Research Project 21-3. A prototype device was built and installed at a bridge for further research and development.



3.52 Tell-tail device



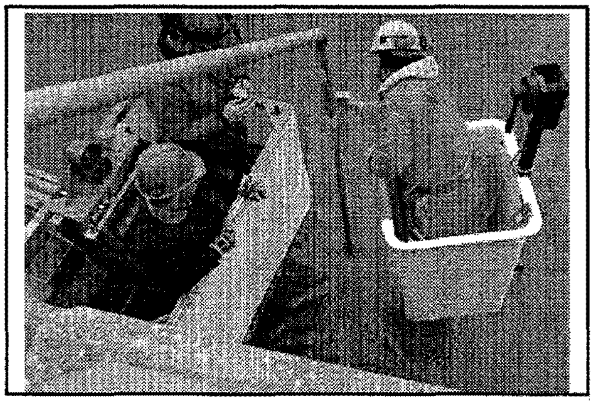
3.53 NCHRP 21-3 Piezofilm device

C. Case histories.

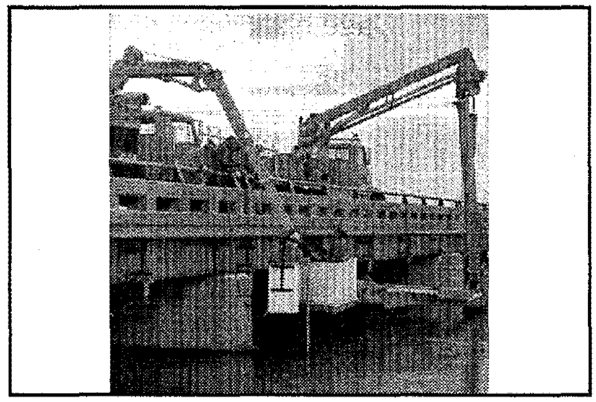
1. Sliding collar device in Michigan.

2. Sliding collar device in New York.

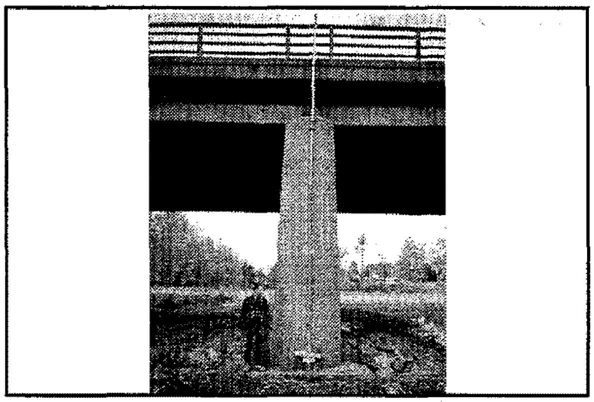
3. Sliding collar device in New Mexico.



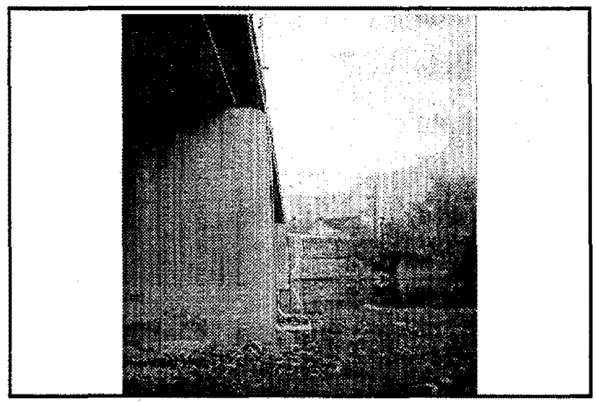
3.54 Muskegon River, Michigan



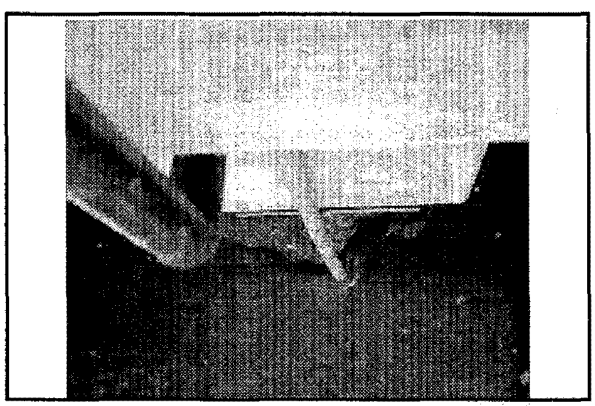
3.55 Installing stainless steel pipe, Michigan



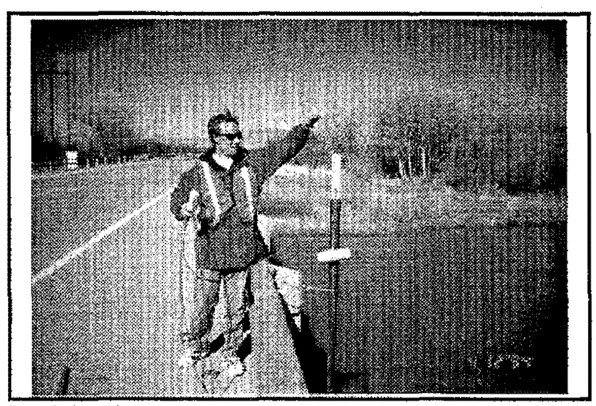
3.56 Middleburg bridge, Schoharie Creek



3.57 Middleburg bridge, Schoharie Creek



3.58 Sliding collar, New Mexico



3.59 Sliding collar measurement New Mexico

VI. OTHER BUREID DEVICES

OTHER BURIED DEVICES
Theory and Operation

- *Sensors buried in the bed at various elevations*
- *As scour occurs sensors roll or float out of the hole*
- *Hydrophone application*

3.60 Other buried devices

A. Theory and operation.

1. This class of device consists of sensors that are buried in the bed of a river at various elevations. Scour detection typically occurs when the sensors become exposed, with the sensors possibly rolling or floating out of the hole. Such sensors could be tethered or untethered.

2. Chain buried vertically in the bed has been utilized on a limited, experimental basis with some success (e.g., Chaco River near Chaco National Monument; USGS, Oregon).

3. Other buried devices include an adaptation of equipment utilized in seismic exploration known as a hydrophone device. A hydrophone is essentially a sound wave receiver. A series of hydrophones buried at various depths detect different sound wave strengths (both direct and refracted sound waves) created by an acoustic pulse generated close to a pier or abutment. Research on the application of this technology to scour measurement is being completed by North American Geotechnical Company, Houston, Texas.

OTHER BURIED DEVICES
Advantages/limitations

- Advantages
  - *Relatively simple in concept*
  - *Relatively low cost*
  - *Not directly affected by debris*
- Limitations
  - *Installation can be a problem in coarse material*
  - *Battery life for electronics*

3.61 Advantages/limitations

B. Advantages and limitations.

Advantages:

- Simple in concept
- Relatively low cost
- Not directly affected by debris

Limitations:

- Installation difficult in coarse bed channels
- Battery power for electronic-based buried devices has a limited life (e.g. shelf life on a lithium battery is typically 5 years) and would require periodic replacement

OTHER BURIED DEVICES
Equipment Sources

- *ETI Instruments, Inc.*

3.62 Equipment sources

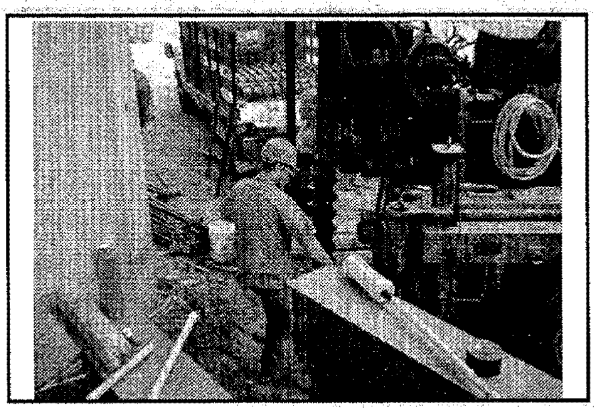
C. Equipment sources.

1. ETI Instruments, Inc., Fort Collins, Colorado (970-484-9393).

D. Case studies.

1. U.S. Highway 101, Salinas River, California.

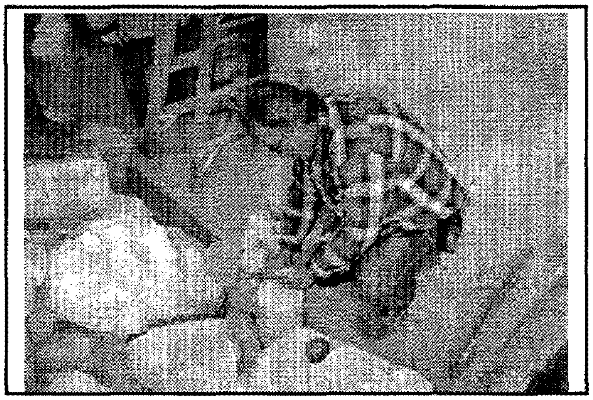
2. I-15,California Wash, Nevada



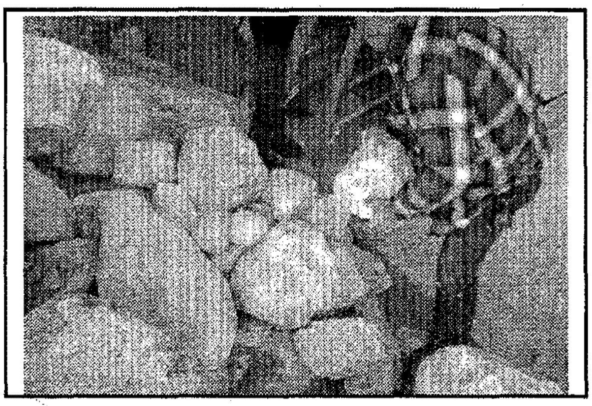
3.63 100-mm float out transmitters

3.64 Hollow stem auger

3.65 Inserting float out transmitter



3.66 150-mm float out in riprap layer



3.67 Placing rock around float out

LESSON 3

FIXED INSTRUMENTATION

PART 2 - DEMONSTRATION

I. SONAR

A. Briefly overview the NCHRP Project 21-3 sonar device.

NOTES:

B. Installation and use.

1. Instrument needs to be protected from elements and vandalism.
2. Transducer mounted directly to pier, or "above-water serviceable."
3. Power provided from 110-volt source, or battery/solar cell.
4. Data logger and/or telemetry can be utilized and is desirable.
5. Minimum depth capability typically about 0.5 m for fish-finder type devices; somewhat less for survey grade devices. Maximum depths exceed 150 m.
6. High sediment concentration or air entrainment can affect readings.
7. Debris buildup can prevent measurement and/or damage transducer.
8. Algae buildup on transducer can be a maintenance problem.
9. Temperature/salinity corrections may be necessary.

C. Strategies for cost-effective installation.

1. Above-water serviceable installations can be designed to allow transducer servicing from a boat, or from the bridge deck (low bridges only).

2. A fixed transducer mounted near the channel bottom may operate better in areas with high debris loading, however, this will require diver installation, inspection and maintenance.

3. For monitoring flood conditions only, a fixed transducer can be mounted just above normal low water elevation, but would be subject to debris problems.

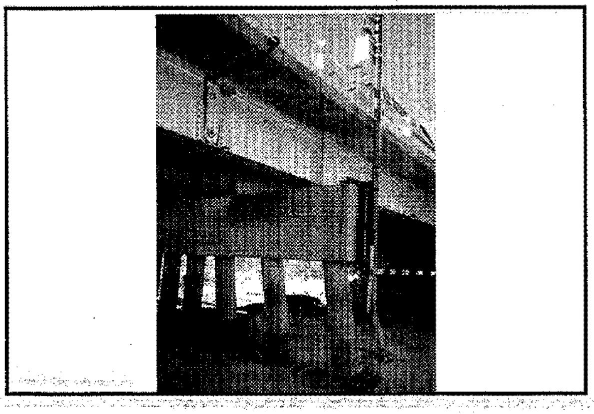
4. Instrument shelters and solar panels should be protected by the guard rail whenever possible to prevent damage from wide loads.

5. Instrument shelters and solar panels should be located, when possible, to minimize vandalism.

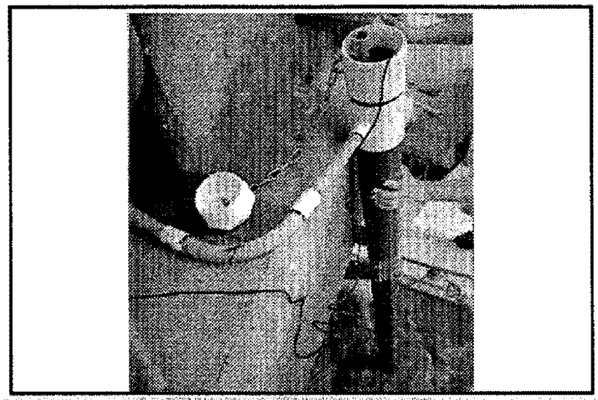
D. Equipment demonstration.

1. NCHRP Project 21-3 sonar instrument.

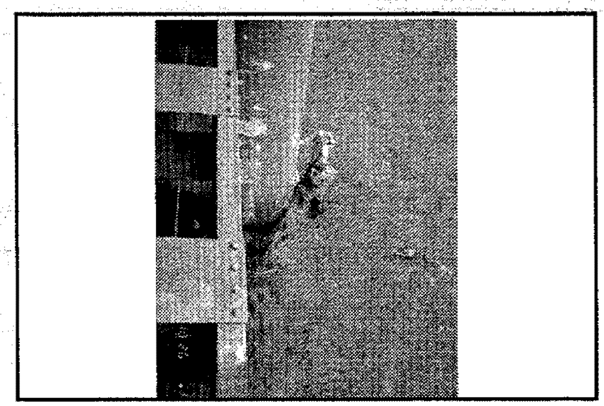
NOTES:



P3.1 Bridge deck serviceable installation photo

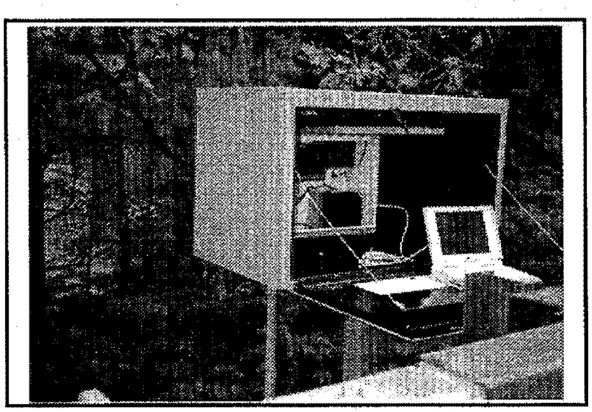


P3.2 Boat serviceable installation

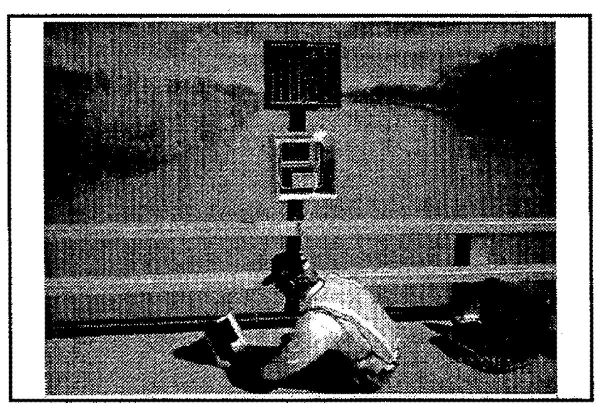


P3.3 Pier installation

P3.4 Pier installation



P3.5 Hudson River instrument shelter



P3.6 Rio Grande instrument shelter

II. FIXED INSTRUMENTATION - SOUNDING RODS

A. Briefly overview the Brisco Monitor Instrument that will be demonstrated.

B. Installation and use.

1. A sounding rod mounted at the front of a pier will be subject to ice and debris impact and loading and must be built and installed to resist such forces. Installation on the side of the pier has been used in some locations.

2. Hydraulic and debris-loading forces limit the total depth (water depth plus scour hole depth) that a sounding rod can extend due to unsupported rod length, vortex shedding, etc.

3. Sliding sounding rods are subject to binding from hydraulic forces and sediment and debris that might be caught by rod.

4. Vertical sounding rods generally perform better than angled sounding rods (as might be applied on an abutment spill through slope).

5. In highly erodible bed conditions (e.g., sand-bed streams), the baseplate must be large enough to minimize the settlement or penetration of the rod into the bed. Research suggests that the bearing stress should be less than about 30 kPa. (NCHRP Project 21-3, Phase I Final Report, Richardson and Lagasse 1992).

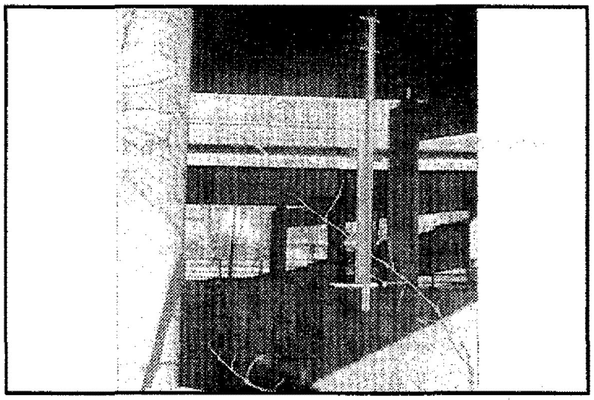
6. If a data logger or telemetry installation is utilized, any instrumentation needs to be protected from elements and vandalism, and power will be required from a 110 volt source or battery/solar cell.

C. Strategies for cost-effective installation.

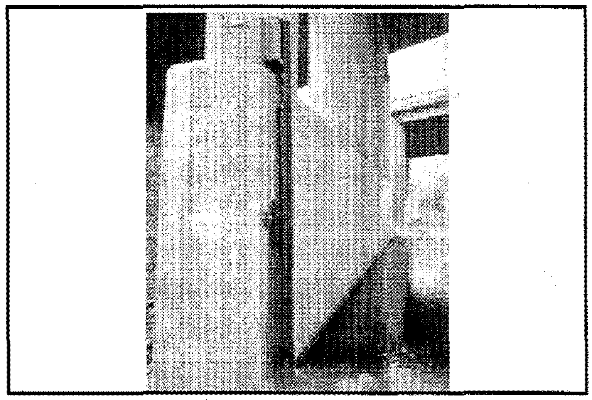
1. The concern for total unsupported length, vortex shedding (as it relates to potentially significant vibration), and bearing stress limitations (in sand-bed channels) suggests that sounding rods are useful for relatively shallow flow depths and scour holes (e.g., less than about 2 m total) on coarse-bed streams.

2. Limited test data suggests that sounding rods may be best suited for piers or abutments where the instrument can be mounted in the vertical direction.

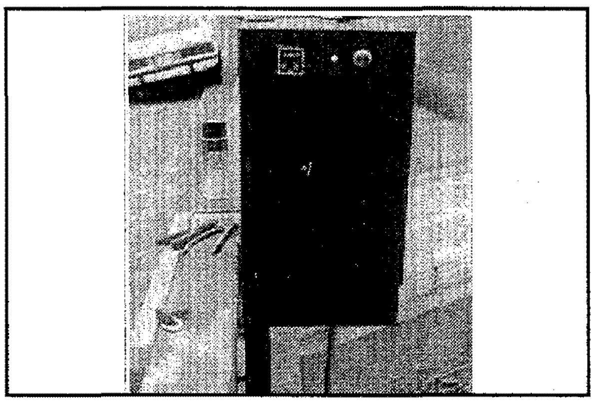
D. Equipment demonstration.



P3.7a Brisco Monitor installation, New York



P3.7b Completed installation, New York



3.8 Instrument shelter, New York

III. FIXED INSTRUMENTATION - BURIED / DRIVEN RODS

A. Briefly overview the NCHRP Project 21-3 magnetic sliding collar instrument that will be demonstrated.

B. Installation and use.

1. Installation of driven/buried rod devices can be a problem. Driven rods must hammered (typically by pneumatic methods) and/or jetted into the streambed. This has not been a limitation for sliding collar devices, but for other electrical and electromechanical devices, this can create problems with the various types of sensors (e.g., sensor damage during installation). Buried rods must necessarily disturb the parent material and then be backfilled, which can be difficult underwater and may alter or even enhance the scour potential.
2. Mechanical devices such as sliding collars are subject to binding and their freedom of movement can be affected by debris, ice, and sediment.
3. The sensors of electrical and electromechanical devices are difficult to waterproof and protect from ice and debris impact forces.
4. As with sounding rods, the problems of unsupported length and vibration from vortex shedding must be considered with buried/driven rods.

NOTES:

C. Strategies in cost-effective installation.

1. Experience has shown that pneumatic driving with a light to medium weight post driver (e.g., Rhino brand PD-40 or PD-50) can drive a 2- inch pipe about 3-4 m into a sand-bed stream. Similar depths were achieved with a jack hammer equipped with a driving adaptor. Heavier weight drivers might achieve greater penetration.

2. Jetting in combination with driving is effective in providing deeper rod penetration; however, this requires a special jetting tip and a source of high pressure water.

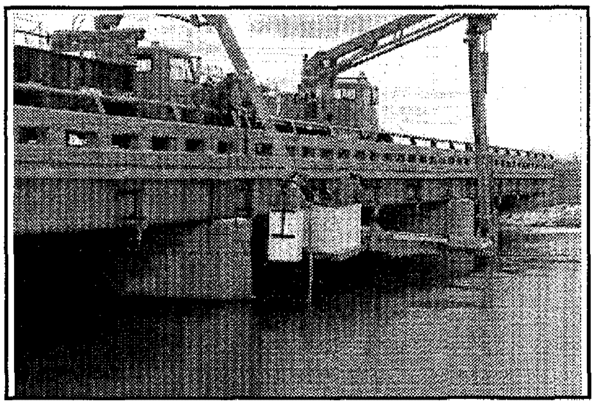
3. Predrilling a hole and burying the rod can be effective when used in relatively homogenous, noncohesive and unconsolidated stream bed material. In a more cohesive, consolidated material, the differences in the backfill material may be a problem, and/or may aggravate scour hole development.

4. The concern for total unsupported length and vortex shedding (as it relates to potentially significant vibration) suggests that buried/driven rods are useful for relatively shallow flow depths and scour holes (e.g., less than 2 m total), unless additional structural support provided.

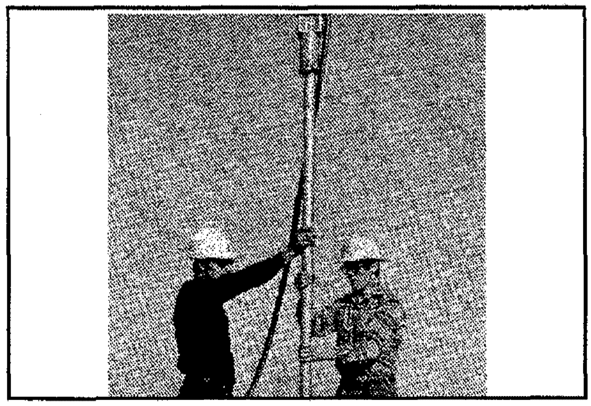
5. Installation is easiest at low-flow conditions or with a coffer dam, when available (i.e., installation under dry conditions).

D. Equipment demonstration.

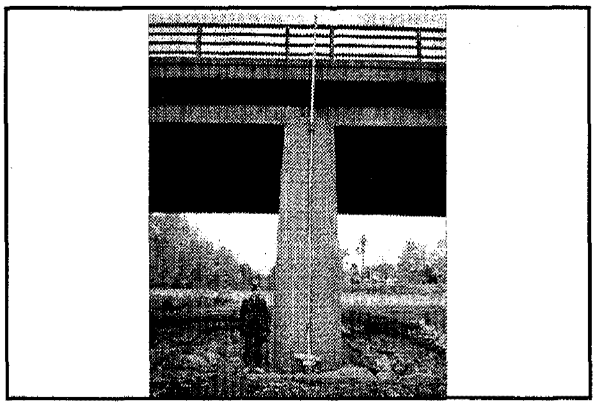
NOTES:



P3.9 Installation using "snooper trucks"

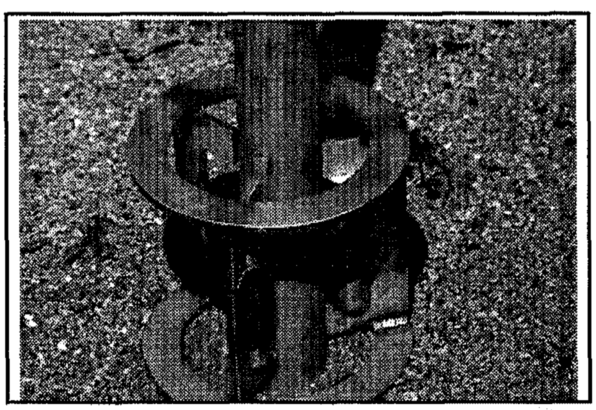


P3.10 Pneumatic post driver installation



P3.11 Sliding collar instrument that was installed in a bore hole

P3.12 Jetting installation



P3.13 Magnetic sliding collar

P3.14 Sliding collar measurement

IV. FIXED INSTRUMENTATION - OTHER BURIED DEVICES

A. Briefly overview the float-out device that will be demonstrated.

B. Installation and use.

1. The float-out transmitters can be installed in a drilled hole, or buried in a riprap pile.

2. The shelf-life of the battery powering the electronics in the float out limits the servicable life of the instrument, unless the battery can be changed. This might be feasible in a riprap installation in a dry stream bed, but otherwise would not be practical.

3. Based on the battery life issue, the best application of a float device may be for emergency or short term monitoring situations (e.g. the bridge is scour critical and scheduled to be replaced in the near future). Float out transmitters may also be useful in combination with another type of fixed instrument to provide additional coverage at a given bridge.

4. The receiver is located in an instrument enclosure located somewhere on the bridge deck. At a minimum, a data logger should be used to record the time that the float out was exposed; however, the real advantage of the float out device is to provide a warning of an impending scour problem and most installations would include telemetry and some type of notification system (pager, voice modem, etc.)

NOTES:

C. Strategies for cost-effective installation.

1. Standard drill rig equipment can be used to drill a hole for installation of a float out transmitter. A hollow-stem auger eliminates the need to case the hole, as the transmitter can be dropped down the auger stem.

2. If there is ground water present, the transmitter, which is buoyant, will have to be pushed down to the bottom of the hole. This can be done with a small diameter pipe or rod. After reaching the bottom of the hole, the hollow-stem auger or the casing can be pulled up 0.5-1.0 m allowing the hole to collapse around the transmitter. The small diameter pipe or rod can then be removed.

3. When burying the float out in a riprap pile, the rock should be hand placed around the float out transmitter. After adequately embedding the float out, rock placement with a loader may be resumed.

4. Different frequencies can be used at different locations. For example, one frequency might be used for the abutments, and another for the piers. Alternatively, one frequency might be used at one elevation, and a different frequency at a deeper elevation, to provide an early warning and then a critical condition alert.

5. The number of frequencies available is limited in part by the receiver power requirements. The receiver must be on all the time, listening for a transmission from a float out that has been exposed. More frequencies will result in higher power requirements. If AC power is available, this should not be a concern, but with battery/solar power, 2-4 frequencies may be all that is practical.

D. Equipment demonstration.

NOTES:

LESSON 4

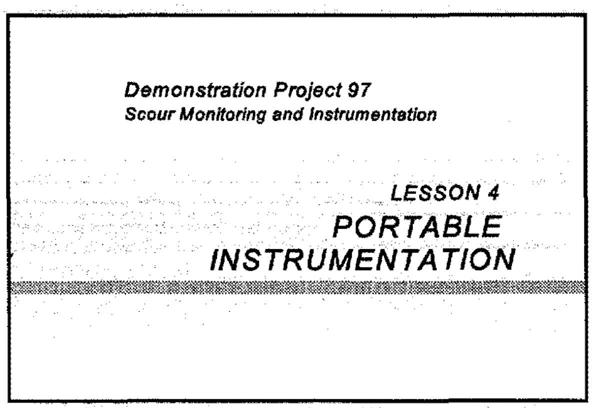
PORTABLE INSTRUMENTATION

OVERVIEW: Method of Instruction: Lecture and Demonstration

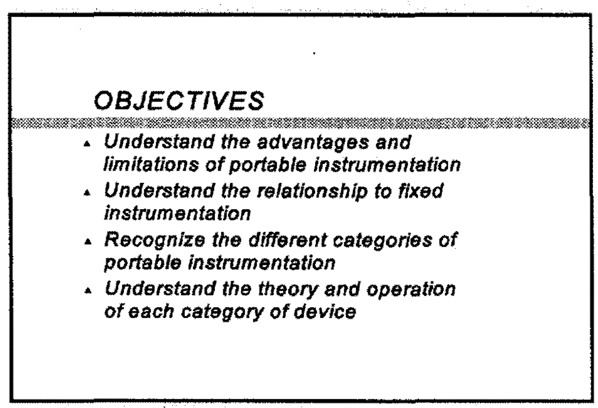
Lesson Length: 45 minutes Lecture
30 minutes Demonstration

Resources:

Lesson Outline
Slides



4.0 Title



4.1 Objectives

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

1. **Understand** the advantages and limitations of portable instrumentation for monitoring bridge scour.

2. **Understand** the relationship to fixed instrumentation.

3. **Recognize** the different categories of portable instrumentation.

4. **Understand** the theory and operation of each category of device.

LESSON 4

PORTABLE INSTRUMENTATION

PART 1 - LECTURE

I. NEED, ADVANTAGES AND LIMITATIONS OF PORTABLE INSTRUMENTATION

II. CATEGORIES OF PORTABLE INSTRUMENTATION

III. PHYSICAL PROBING

IV. SONAR INSTRUMENTS

PART 2 - DEMONSTRATION

LESSON 4

PORTABLE INSTRUMENTATION

PART 1 - LECTURE

I. NEED, ADVANTAGES AND LIMITATIONS OF PORTABLE INSTRUMENTATION

NEED FOR PORTABLE INSTRUMENTATION

- *Definition*
  - *Portable instrumentation is instrumentation that can be readily moved from one location to another*
- *Used when a bridge does not have a fixed instrument, or when additional measurements are desired*
- *Can be used to measure both local and contraction scour*

4.2 Need for portable instrumentation

A. Need for portable instrumentation.

1. Portable instrumentation is instrumentation that can be readily moved from one location to another, either at a given bridge or from one bridge to another.

2. Portable instrumentation is used when a bridge does not have a fixed instrument, or when scour measurements at a location other than the fixed instrument location are desired.

3. Fixed instrumentation is used primarily to evaluate local scour conditions at a given pier or abutment. In contrast, portable instrumentation can be used to evaluate both local scour or scour over a larger areal extent, such as contraction scour conditions.

PORTABLE INSTRUMENTATION
Advantages

- *More bridges can be investigated, and more area at a given bridge*
- *Point measurement or complete bathymetric mapping*
- *Rapidly mobilized during flood and emergency situations*
- *Can detail scour conditions (scour hole, bedform, thalweg, etc)*
- *Effective as part of regular bridge inspection program*

4.3 Advantages of portable instrumentation

B. Advantages of portable instrumentation.

1. With portable equipment more bridges can be investigated with the same equipment and also more area covered at any given bridge.

2. Portable equipment can be used for point measurement (similar to fixed instrumentation) or complete bathymetric mapping (with appropriate positioning equipment).

3. The ability to rapidly mobilize portable instrumentation is valuable for flood and emergency measurements.

4. Portable instrumentation can be used for detailing specific scour conditions, such as a scour hole at a pier, dune form movement, thalweg shifting, etc.

5. Portable instrumentation can be an effectively used as a part of the regular bridge inspection program.

PORTABLE INSTRUMENTATION
Limitations

- *Only monitor discrete points in time and space*
- *Can be labor intensive*
- *May require special platforms, such as boats or trucks, although hand-deployed systems have been effective*

4.4 Limitations of portable instrumentation

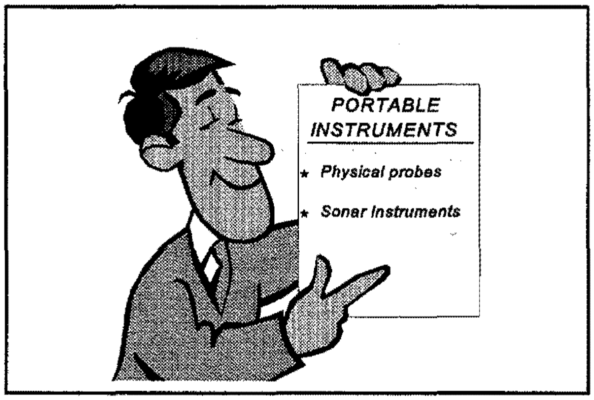
C. Limitations of portable instrumentation.

1. Only monitoring at discrete points in space and time.

2. The use of portable instrumentation can be labor intensive.

3. The use of portable instrumentation may require special platforms for use, such as boats or trucks or truck-mounted articulated booms, although hand-deployable systems have proven effective for many applications.

II. CATEGORIES OF PORTABLE INSTRUMENTATION



4.5 Categories of portable instrumentation

A. For purposes of scour monitoring and instrumentation two categories of portable instrumentation are defined: physical probes and sonar instruments.

B. While geophysical instruments are "portable," they are not generally used for real time data collection, but rather for forensic purposes. In the context of our definition, portable instrumentation for scour monitoring provides a "snapshot" of current conditions. In contrast, geophysical instruments provide a insight on historical or long-term temporal changes scour conditions based on measurements taken at a later time.

III. PHYSICAL PROBING

PHYSICAL PROBES
Theory and Operation

- ***Physical probes are any type of mechanical device that extends the reach of the person making an inspection***
- ***Physical probes have been in use for a long time***

4.6 Physical probing

A. Theory and operation.

1. Physical probes are any type of mechanical device which extends the reach of the person making an inspection.

2. Scour detection by physical probes have been used as long as humans have been constructing engineering works in and over water.

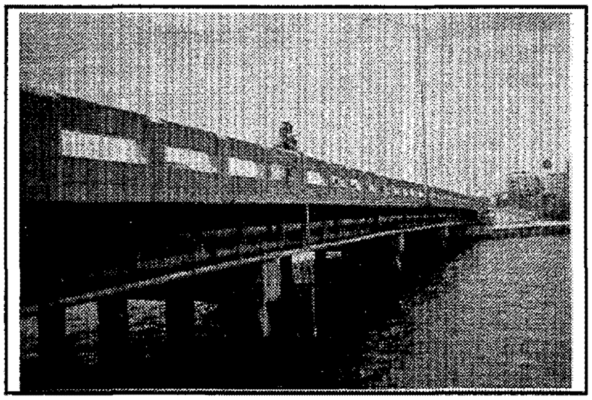
SOUNDING POLES
OR LEAD LINES

- ***Sounding poles are long poles used to probe the bottom***
- ***Lead lines are weighted lines***
- ***Can be used from the bridge, a boat or wading***
- ***Effectiveness may be limited by depth and velocity***

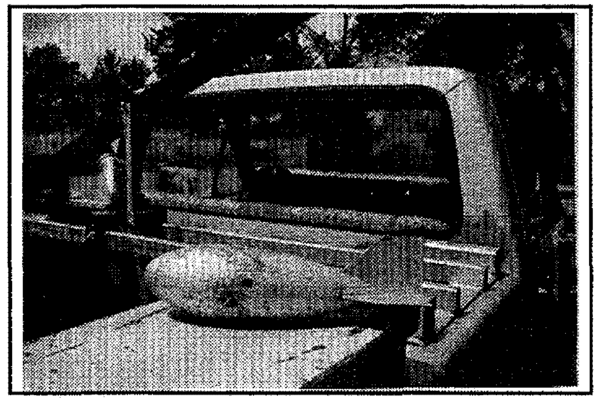
4.7 Sounding poles and lead lines

B. Sounding poles or lead lines.

1. Sounding poles are long poles used to probe the bottom; lead lines are weighted lines, typically a torpedo-shaped weight suspended by a graduated steel cable.



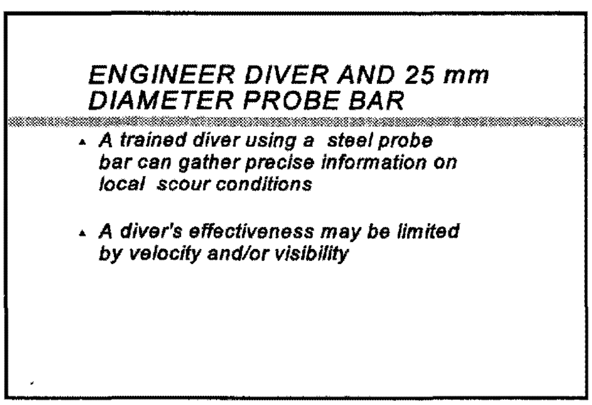
4.8 Sounding pole measurement



4.9 Lead-line measurement

2. These devices can be used from the bridge, a boat, or by wading. The experienced inspector may also be able to discern bottom material type as well as location. Infilled material in a scour hole is often loose and can be penetrated easier than the surrounding streambed.

3. The effectiveness of sounding poles and lead lines can be limited by depth and velocity. However, cross sections taken at the 2-year inspection would often be at low-flow conditions where a sounding pole or lead-line is effective and cost-efficient.



4.10 Engineer diver

C. Engineer diver and 25 mm diameter probe bar.

1. A trained diver using a steel probe bar can gather very precise data regarding local scour and the upper layer of any infilled material.

2. For general scour observation, divers are less useful because of the difficulty in maintaining orientation. A diver's effectiveness is limited primarily by water velocity. Visibility is also a consideration.

PHYSICAL PROBING
Advantages/limitations

- *Advantages*
  - *simple, direct measurement*
  - *low cost*
  - *no specialized training (except when using diver)*
- *Limitations*
  - *difficult or impossible at high flow*
  - *may be difficult to define channel bottom in soft materials*
  - *does not provide a continuous profile*

4.11 Advantages/limitations

D. Advantages and limitations.

Advantages:

- Simple, direct technology for scour measurement
- Low cost
- No specialized training, except when using a diver

Limitations:

- Difficult or impossible at high flow or flood conditions.
- Can be difficult to accurately define bottom location in soft materials
- Does not provide a continuous profile across the channel

PHYSICAL PROBES
Equipment Sources

- *25-ft fiberglass survey rods are useful under low-flow conditions*
- *Lead-line equipment (sounding weight, sounding reel, hand reel/tagline) commonly used in stream gaging*

4.12 Equipment sources

E. Equipment sources.

1. Twenty-five-foot fiberglass survey rods are useful for probing under low-flow conditions and are readily available.

2. Lead-line equipment (sounding weight, sounding reel, hand reel or tagline) are commonly used in stream gaging. Sources include Teledyne Gurley (518-272-6300) and Scientific Instruments Inc. (414-263-1600).

IV. SONAR INSTRUMENTS

SONAR INSTRUMENTS
Theory and Operation

- *Measurement based on velocity of sound (see Lesson 3)*
- *Typically operate at about 200 kHz*
- *Provide accurate depth information, but little or no subbottom information*
- *Color sonar*

4.13 Sonar theory and operation

A. Theory and operation.

1. Sonar instruments (also called electronic echo sounders, fathometers or acoustic depth sounders) measure the elapsed time that an acoustic pulse takes to travel from a generating transducer to the waterway bottom and back. See Lesson 3 for more discussion on the theory of sonar instruments.

2. Sonar instruments operate at mid-range acoustical energy spectrum (≈ 50-1000 kHz). As discussed in Lesson 3, the most common frequency is 200 Khz for single-frequency systems.

3. Sonars provide accurate depth information, but little or no subbottom information. A sonar operating at a low frequency has a limited ability to detect reflected energy from subbottom interfaces (e.g., an infilled scour hole).

4. A color fathometer is calibrated to measure and display in color, the amplitude of the reflected signal which can be related to the characteristics of the subbottom.

SONAR INSTRUMENTS
Portable Application

- *low-cost fish-finders to survey grade instruments*

4.14 Application

4.15 Portable sonar system in use

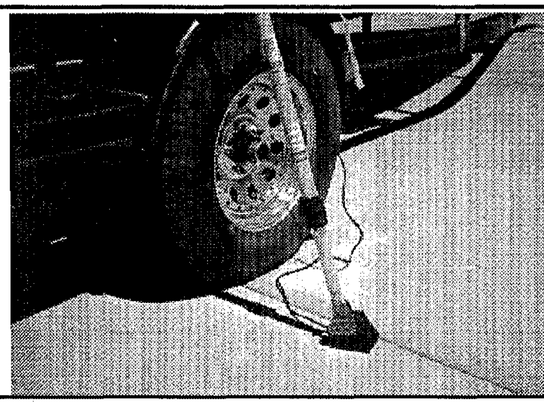
B. Application of sonar instruments as portable devices.

1. Sonar instruments suitable for portable application include the same type of devices used for fixed instrument application, ranging from low-cost "fish-finders" with an LCD to survey grade instruments that have paper printout and can be calibrated.

SONAR INSTRUMENTS
Portable Application

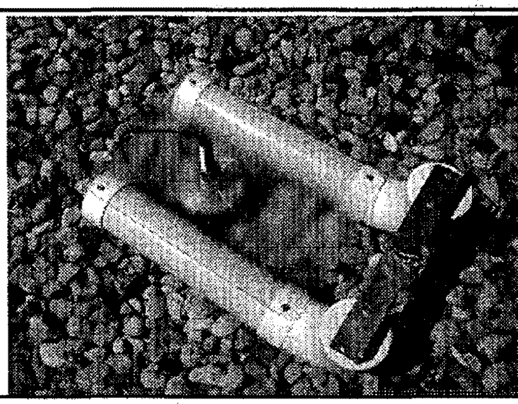
- *low-cost fish-finders to survey grade instruments*
- ***Deployment from bridge or boat***

4.16 Application (cont)



4.17 Transducer mounted to pole

2. Portable sonar instrumentation may be deployed from the bridge or a boat. Bridge deployment requires suspending the transducer from the bridge, either on a long pole or with some type of float. Float systems range from pontoon floats made of PVC pipe to water skis/kneeboards or specially fabricated floats.



4.18 Pontoon float

4.19 Kneeboard float

SONAR INSTRUMENTS
Portable Application

- *low-cost fish-finders to survey grade instruments*
- *Deployment from bridge or boat*
- ***Vertical datum adjustment required***

4.20 Application (cont)

SONAR INSTRUMENTS
Portable Application

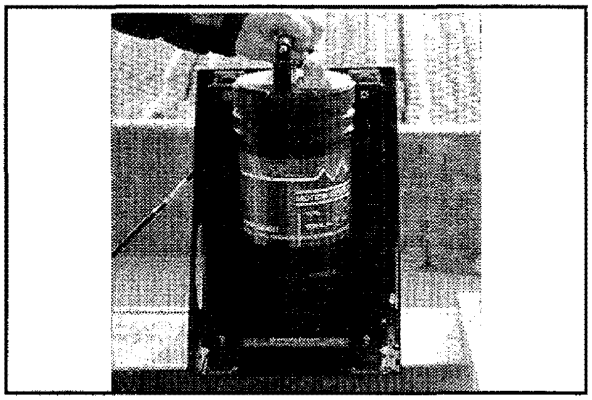
- *low-cost fish-finders to survey grade instruments*
- *Deployment from bridge or boat*
- *Vertical datum adjustment required*
- ***Corrections required for draft, pitch/roll and stage changes***

4.21 Application (cont)

3. The sonar measures the depth from the transducer location, which should be adjusted to some local vertical datum, such as the bridge deck or a survey vertical datum (eg. NGVD).

4. Depending on the accuracy required, corrections to the sonar reading should be made for draft on the transducer, and for boat or float measurements correction for pitch and roll and potential variations in stage (water surface elevation) during the measurement.

   The draft correction is based on the distance the transducer is below the water surface. For boat deployment, the measured depth should be corrected for short-term vessel draft variations due to loading changes and squat.



4.22 Heave, pitch and roll sensor

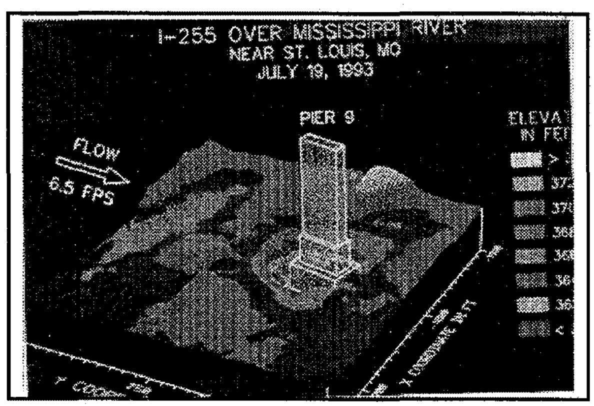
Pitch and roll of the boat cause the sonar to read an angled distance rather the perpendicular distance to the bottom. For precise survey work, instruments are available that record the pitch and roll of the boat allowing the sonar depth to be corrected, usually as a post-processing step.

Stage variations can occur due to time varying discharge or tides. A correction for stage can be made by recording time along with depths and then post processing depths with a stage history data set to correct for the stage variation.

SONAR INSTRUMENTS
Portable Application

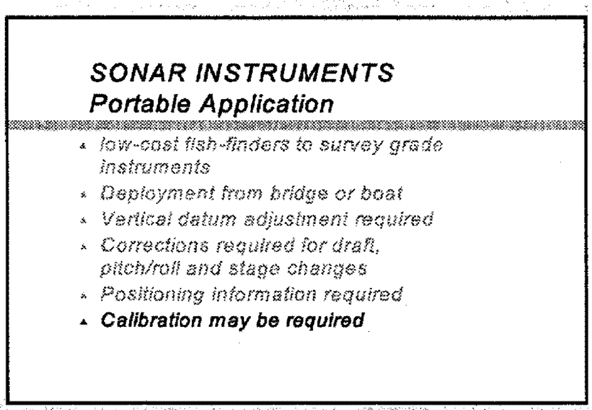
- *low-cost fish-finders to survey grade instruments*
- *Deployment from bridge or boat*
- *Vertical datum adjustment required*
- *Corrections required for draft, pitch/roll and stage changes*
- ***Positioning information required***

4.23 Application (cont)



4.24 Bathymetric mapping near pier

5. Positioning information is required, ranging from relative position based on bridge piers to horizontal position measured along bridge deck to precise coordinate systems. Bathymetric mapping is possible with precise positioning systems, allowing accurate mapping of a scour hole or a complete reach of river. Positioning systems will be discussed in Lesson 5.



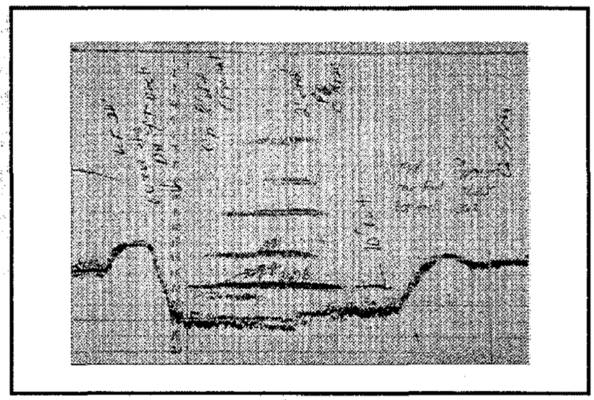
4.25 Application (cont)

6. Survey grade sonar instruments can be calibrated to site specific conditions. The only effective method of determining the correct depth is by a bar check calibration, which is the process of suspending a metal bar or other target a known distance below the transducer to verify echo sounder accuracy.

SONAR INSTRUMENTS
Portable Application

- *low-cost fish-finders to survey grade instruments*
- *Deployment from bridge or boat*
- *Vertical datum adjustment required*
- *Corrections required for draft, pitch/roll and stage changes*
- *Positioning information required*
- *Calibration may be required*
- ***Should review data for potential errors***

4.26a Application (cont)



4.26b Chart with side echo

7. Upon completion of data collection, before leaving the site, examine all results so any bad or missing data can be immediately re-taken. Conditions which can cause erroneous data collection or missing data include: excessive turbulence, suspended solids, supersaturated gas concentrations, side reflections from piers and walls, and multiple bottom reflections.

SONAR INSTRUMENTS
Advantages/limitations

- *Advantages*
  - ***point measurement or complete mapping***
  - ***simple to use***
  - ***accurate***
  - ***easily deployed***
- *Limitations*
  - ***can be difficult to use at high flow***
  - ***deployment off bridge limited to low bridges***

4.27 Advantages/limitations

C. Advantages and limitations.

Advantages:

- Point measurement or complete bathymetric mapping
- Simple to use

- Accurate
- Easily deployed

Limitations:

- Difficult, but not impossible, to use in high flow or flood flow conditions
- Operation from bridge only possible on low bridges

SONAR INSTRUMENTS
Equipment Sources

- *"Fish finder" type devices readily available from boat/marine sources*
- *Other sonar devices. Odom, Innerspace, Ross Laboratories, etc.*

4.28 Equipment sources

D. Commercially available devices.

1. "Fish finder" devices - See any boat/marine products catalog or boat/marine store (e.g., West Marine (800-538-0775), Bass Pro Shops (800-227-7776), and Cabela's (800-237-4444).

2. Other sonar devices - Odom Hydrographic Systems, Inc., Baton Rouge, Louisiana (504-769-3051), Innerspace Technology, Inc., Waldwick, New Jersey (201 447-0398), Ross Laboratories, Inc., Seattle, Washington (206-324-3950).

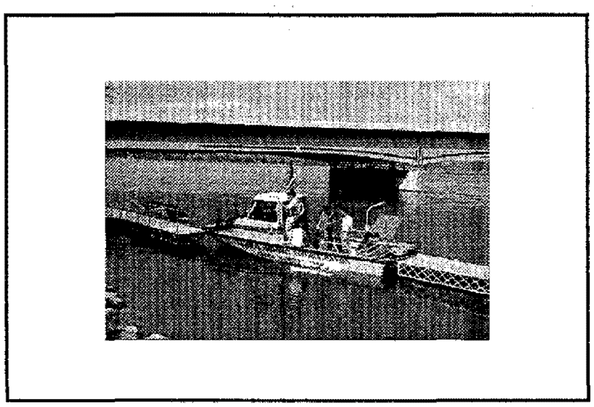
E. Case studies.

1. FHWA boat: The FHWA has a 25-foot Boston Whaler boat with twin 200-horsepower outboard engines that has been used for scour monitoring. The boat is equipped with black and white sonar, a 3.5 kHz subsurface profiling system with a towed pontoon-mounted transducer and a GPR with a boat mounted-antenna.

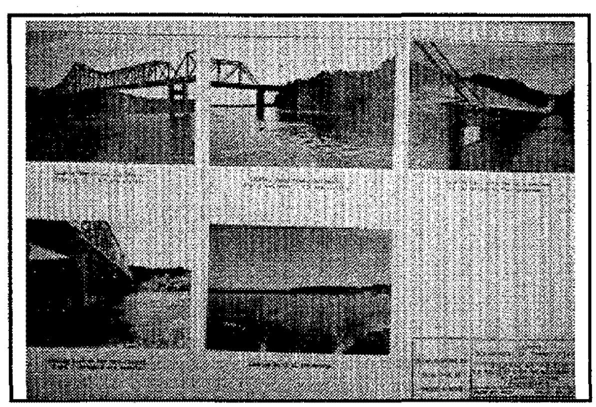
   This boat was used during the 1993 Mississippi river flood to monitor a number of bridges. This case study illustrates one of those bridges.

   The FHWA boat is available for field demonstrations, or for use on a specific project. Contact Mr. Tom Krylowski, FHWA (202-366-6771).

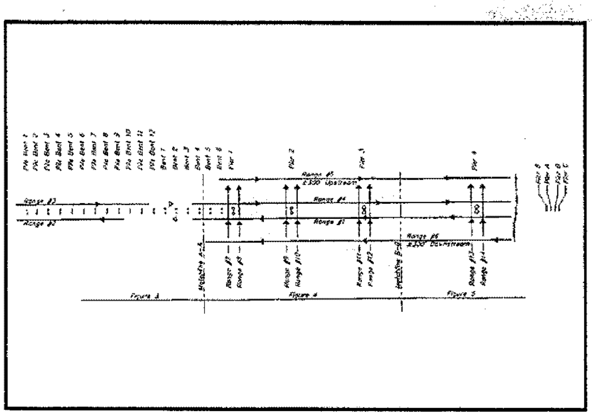
2. USGS remote control boat: The USGS, under FHWA funding, has built an experimental remote controlled boat. The boat is a small jon boat with an outboard motor. The sounding instrument is a digital fathometer, and horizontal control is by a range-azimuth based hydrographic survey system. An on-board computer will monitor vessel instrumentation, record measured data and telemeter data to shore.



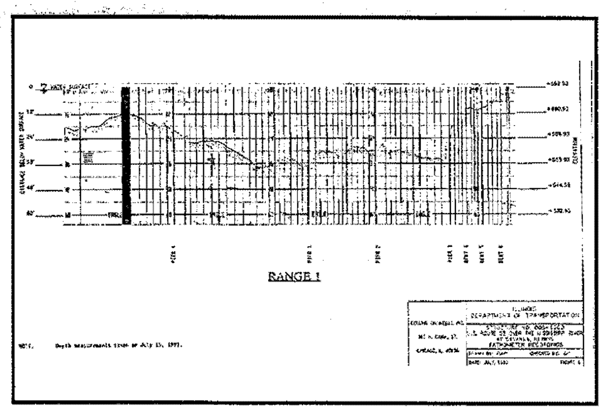
4.29a FHWA boat



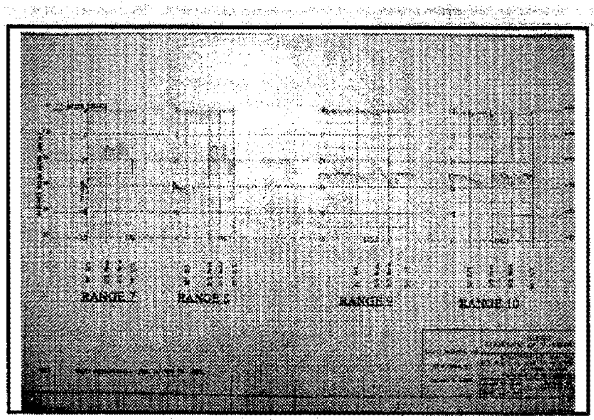
4.29b Bridge photographs



4.29c Range key plan



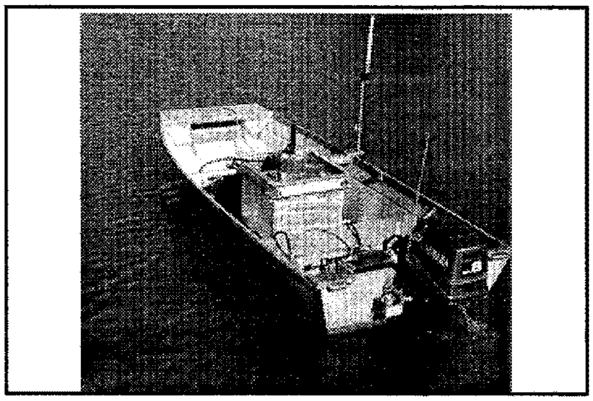
4.29d Echo sounder plot



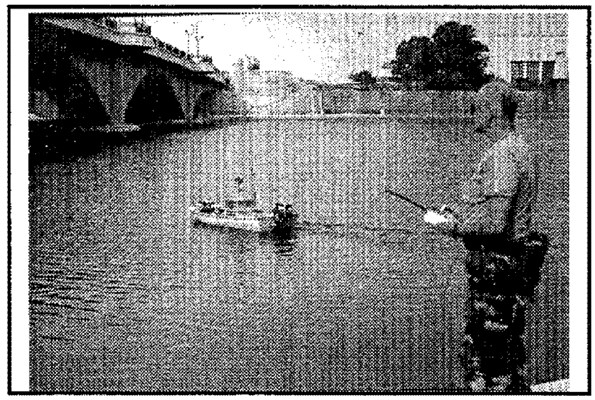
4.29e Echo sounder plot

A smaller remote control, unmanned survey boat is available (for sale or lease) from Innerspace Technology, Inc. The 50-pound system includes a digital depth sounder, data telemetry, and automated range azimuth positioning.

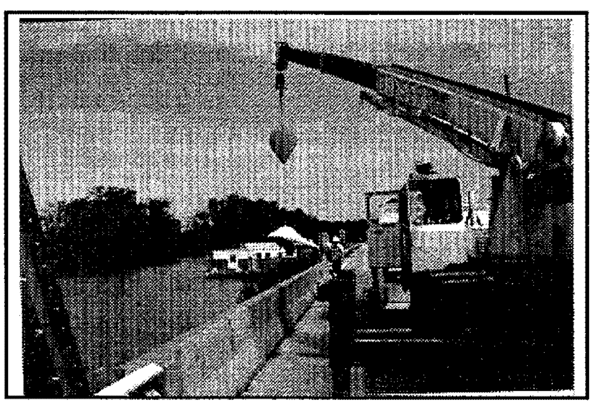
3. <u>AIDI ScourVision™</u>: American Inland Divers, Inc., has developed ScourVision™, a rotating and sweeping 675-kHz, narrow beam (1.8°) sonar system that is deployed from a crane on the bridge. The transducer is mounted in a large hydrofoil that can submerge the transducer in velocities exceeding 20 fps. The system provides real time, 3-dimensional results.



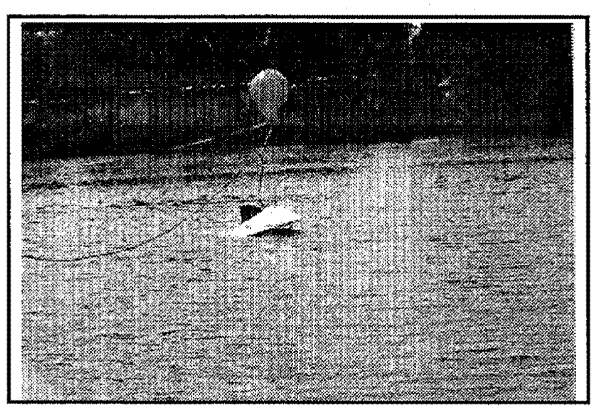
4.30a USGS remote control boat



4.30b USGS boat



4.31a AIDI system, Sabula, Iowa, 1993



4.31b AIDI system, Sabula, Iowa, 1993

NOTES:

NOTES:

LESSON 4

PORTABLE INSTRUMENTATION

PART 2 - DEMONSTRATION

I. PORTABLE INSTRUMENTATION

A. Briefly overview the portable instrumentation that will be demonstrated.

1. Sounding weight with a hand line.
2. Eagle SupraPro ID portable sonar with pontoon float/rod suspension.
3. ETI portable sonar with float.
4. Lowrance X-16 paper chart fish-finder.
5. Echotrac DF 3200 MKII (Odom).

B. Practical aspects of mobilization.

1. Simple portable systems (sounding weights, low-cost sonar with rod/float suspension) deployed from the bridge deck are rapidly mobilized; however, traffic control may be necessary on narrow bridges.

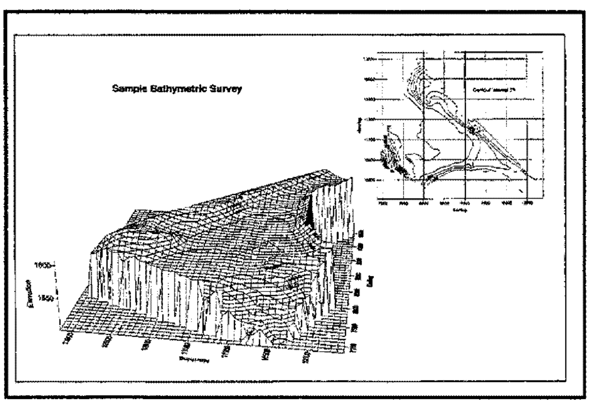
2. More detailed bathymetric surveys require greater planning and mobilization efforts. The number of range lines depends on the bathymetry and the accuracy/resolution required. Photo 4.7 shows a bathymetric map created from range lines 15 m apart and points on each range line 3 m apart, resulting in a total of about 15,000 data points.

   - Safe access is required to the water body and site to be monitored. Flood and normal conditions may pose very different access problems.

   - When using a boat, plan the route to be followed when taking the soundings. Wind and water velocities can make the planned route difficult to follow.

3. Personnel must observe traditional safety practices and procedures of the U.S. Coast Guard and OSHA.

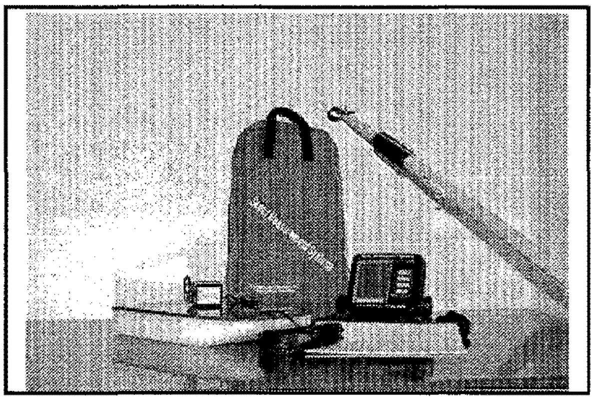
4. The equipment is generally lightweight and easy to use; however, it must be maintained and in good working order.



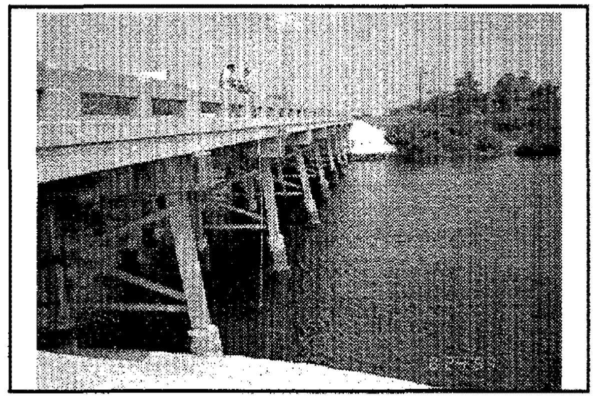
P4.1 Bathymetric map

C. Equipment demonstration.

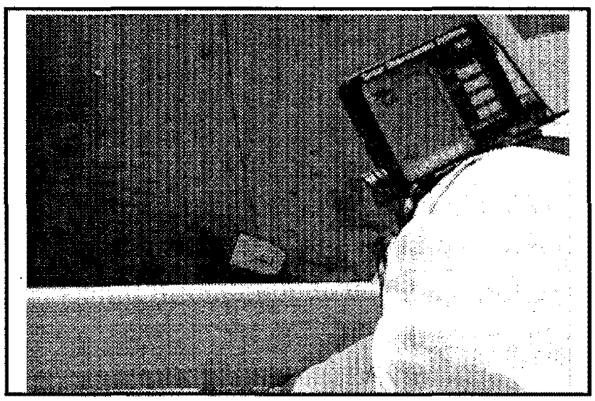
1. Sounding weight.
2. Fish-finder with rod suspension.
3. ETI portable sonar with float suspension.
4. Lowrance X-16.
5. Echotrac DF 3200 MKII.



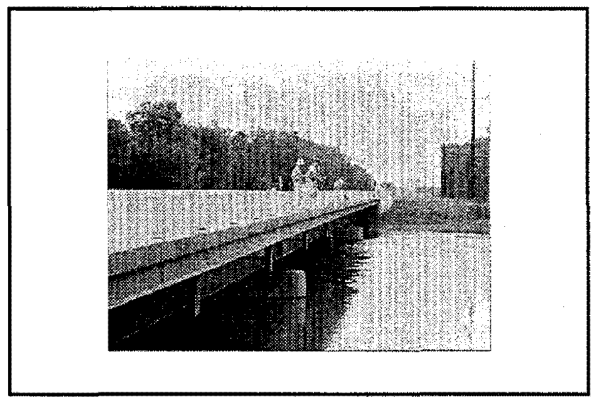
P4.2 Low-cost fish-finder



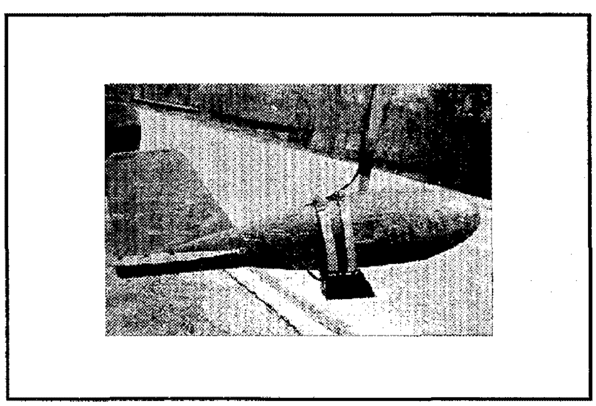
P4.3 Fish finder with rod suspension



P4.4 Float suspension



P4.5 Kneeboard



P4.6 Sounding weight with transducer

P4.7 Survey grade echo sounder

LESSON 5

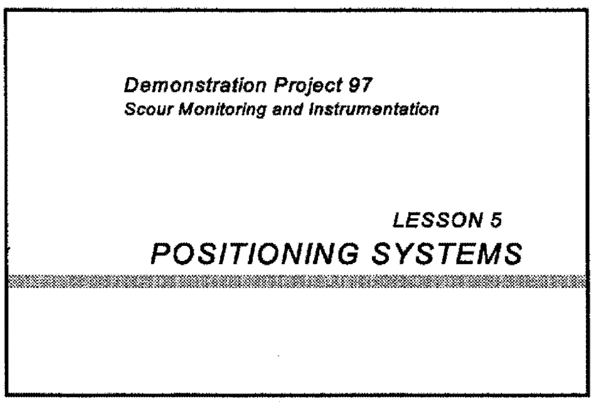
POSITIONING SYSTEMS

OVERVIEW: Method of Instruction: Lecture and Demonstration

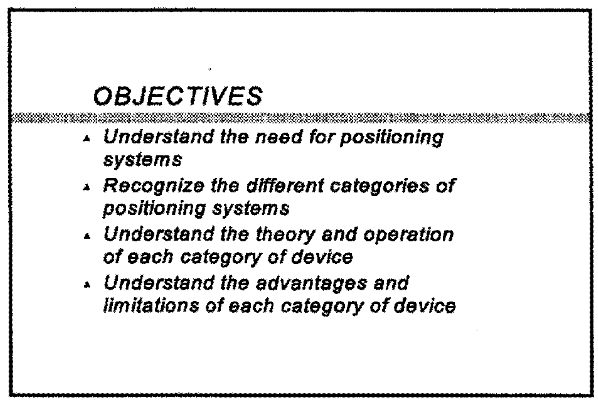
Lesson Length: 45 minutes Lecture
60 minutes Demonstration

Resources:

Lesson Outline
Slides
COE EM 1110-2-1003 "Hydrographic Surveying"
Manufacturers Information



5.0 Title



5.1 Objectives

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

1. **Understand** the need for positioning systems.

2. **Recognize** the different categories of positioning systems.

3. **Understand** the theory and operation of each category of device.

4. **Understand** the advantages and limitations of each category of device.

LESSON 5

POSITIONING SYSTEMS

PART 1 - LECTURE

I. NEED FOR POSITIONING SYSTEMS

II. CATEGORIES OF POSITIONING SYSTEMS

III. APPROXIMATE LOCATION METHODS

IV. VISUAL RANGE INTERSECTION

V. TAG LINE SURVEY

VI. SIMPLE RANGE-AZIMUTH

VII. AUTOMATED RANGE-AZIMUTH

VIII. GLOBAL-POSITIONING SYSTEMS

PART 2 - DEMONSTRATION

I. HAND-HELD LASER DISTANCE METERS

II. AUTOMATED RANGE-AZIMUTH

III. DATA REDUCTION

LESSON 5

POSITIONING SYSTEMS

PART 1 - LECTURE

I. NEED FOR POSITIONING SYSTEMS

NEED FOR POSITIONING SYSTEMS

- *Provide location information when using portable or geophysical instruments*
- *Location information required to evaluate temporal changes in scour*
- *Can range from simple descriptions to precise surveys*

5.2 Need

A. Positioning systems provide location information for scour measurements made with portable or geophysical instrumentation.

B. Location information is necessary to accurately evaluate changes in scour conditions from one measurement to the next.

C. Positioning systems range from very simple location descriptions, such as "about 1 m in front of pier 3," to very precise surveys using total stations, specialized hydrographic surveying equipment, or global positioning systems (GPS).

FACTORS INFLUENCING LOCATION INFORMATION

- *Level of detail or resolution required*
- *Type of inspection*
- *Resources available*

5.3 Location information

D. The type of location information required depends on a variety of factors:

1. Level of detail or resolution required.

   For example, the maximum local scour depth at a pier could be monitored with a simple positioning system approximately locating one point in space; however, detailing a complete scour hole requires a precise positioning system to accurately map the 3-D conditions in the scour hole.

   In contrast, evaluating contraction scour conditions or channel changes in a bridge reach requires positioning information over a large area. For this situation there are also simple methods available, suitable for a reconnaissance level mapping study, and very precise methods using hydrographic surveying equipment, suitable for preparing an accurate bathymetric map.

2. Type of inspection.

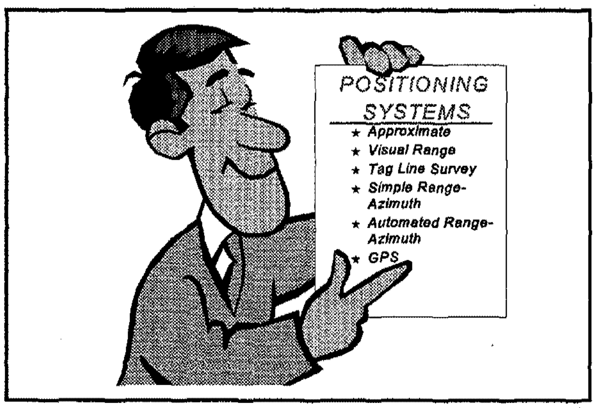
   For example, a routine inspection (e.g., 2-year inspection) might involve a fairly comprehensive set of measurements with detailed positioning information to allow accurate comparison of changes in a scour hole or channel cross section over time. In contrast, emergency monitoring during flood situations might involve only a quick measurement of the maximum scour depth to evaluate bridge safety, or complete detailing of a scour hole if the bridge is considered at risk of failure.

3. Resources available for the inspection.

   Data collection and reduction for detailed positioning information can be time consuming. The resources necessary for this level of detail may not always be available.

NOTES:

II. CATEGORIES OF POSITIONING SYSTEMS



5.4 Categories

A. Approximate location methods.

B. Visual range intersection.

C. Tag line survey.

D. Simple range-azimuth.

E. Automated range-azimuth.

F. Global positioning systems (GPS).

III. APPROXIMATE LOCATION METHODS

> *APPROXIMATE METHODS*
> *Theory and Operation*
>
> - ***Used with probing or sonar measurement from bridge deck***
> - ***Position description based on bridge characteristics***
> - ***Can reference depth measurement to distance along bridge***
> - ***Distance measured from abutment***
> - ***Some bridges marked for stream gaging***

5.5 Theory and operation

A. Theory and operation.

1. Typically involves a probing or portable sonar measurement taken from the bridge deck in the vicinity of a pier or abutment.

2. Positioning information based on bridge characteristics, e.g., "about 1 m upstream of pier 3, or "...halfway between piers 3 and 4."

3. A more accurate position across the channel can be quickly acquired by referencing the depth measurement to a measured distance across the bridge deck.

4. Distance measurement can be made using a long survey tape (e.g., fiberglass tape) beginning at an abutment.

5. Note that bridges used for stream gaging typically have some type of permanent distance marks at a constant interval, such as paint marks, chisel marks in the concrete, small bathroom tiles glued to the concrete, etc. Similar markings could be added to a bridge that is not used for stream gaging, but that will be frequently monitored for scour.

APPROXIMATE METHODS
Advantages/limitations

- *Advantages*
  - *good for reconnaissance and/or some emergency work*
  - *appropriate for cross section measurement during two-year inspection cycle*
  - *low-cost*
  - *no specialized training*
- *Limitations*
  - *limited value for temporal comparisons*
  - *cannot provide detail or 3-D information*

5.6 Advantages and limitations

B. Advantages and limitations.

Advantages:

- Useful for reconnaissance-level and/or some emergency work during flood situations when many bridges must be inspected in a short time period to identify potential scour-critical situations.
- Reconnaissance-level cross sections taken during the 2-year inspection cycle are useful for evaluation of long-term channel changes.
- Low-cost.
- No specialized training.

Limitations:

- Limited value for comparison of scour hole or channel changes from one measurement to the next.
- Cannot provide a detailed, or 3-dimensional perspective, of scour hole geometry.

APPROXIMATE METHODS
Equipment Needed

- *Tape measure*
- *Bridge plans (if necessary to locate identifiable bridge features)*
- *Spray paint, chisel, or tiles (to mark bridges that will be monitored frequently)*

5.7 Available devices

C. Equipment needed.

1. Tape measure.

2. Bridge plans (if necessary to locate identifiable bridge features).

3. Spray paint, chisel, or tiles (to mark bridges that will be monitored frequently).

IV. VISUAL RANGE INTERSECTION

VISUAL RANGE INTERSECTION
Theory and Operation

- *Provides reconnaissance level positioning when using a boat*
- *Range lines identified by visual targets*
- *Chart recording sonar generally used*
- *Method assumes targets available and boat speed constant*
- *Typical inspection includes intersecting range lines*

5.8 Theory and operation

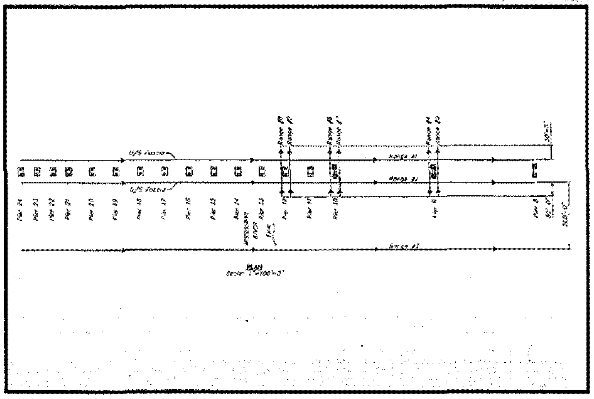
A. Theory and operation.

1. Visual range intersection provides a simple method to get reconnaissance-level information when working from a boat. A range line is the straight line between two identifiable features.

2. The method involves surveying a grid of range lines, with the range lines identified by visual targets. Typically, a chart recording sonar is used for sounding.

3. This method assumes identifiable features are located and a constant boat speed can be maintained.

4. A typical scour monitoring bridge inspection might consist of 4 ranges run perpendicular to the direction of flow (or parallel to the bridge) and ranges parallel to the direction of flow (or parallel to the piers).



5.9 Typical range configuration

VISUAL RANGE INTERSECTION
Theory and Operation (cont)

- *Available targets may be supplemented with ranges poles/flags*
- *Based on constant vessel speed, intermediate sounding locations based on interpolation*
- *Modification of method involves simple distance devices, eg. hip chain*

5.10 Theory and operation (cont)

5. Identifiable features include navigational aids, beacons, day markers, bridges and other structures or map features. It may be useful to set additional range poles and/or flags ashore.

6. Location fixes are taken visually and a constant speed is maintained to the next identifiable object or range intersection. Intermediate soundings are interpolated between the two fixes. The plotted features are presumed to be error free, and a constant vessel speed is assumed to have occurred between the control features.

7. Ranges established by sighting across such features or additional shore points may be intersected for position determination.

8. A modification of this method involves a simple distance measuring device, such as a hip chain or a hand-held laser electronic distance meter (EDM), to provide a distance measurement across the channel (a hip chain is a low-cost device that measures distance based on the length of disposable cotton string pulled through a counter).

VISUAL RANGE INTERSECTION
Advantages/limitations

- *Advantages*
  - *provides reconnaissance level bathymetric mapping*
  - *no specialized equipment necessary*
  - *useful during flood/emergency work*
- *Limitations*
  - *limited accuracy*

5.11 Advantages and limitations

B. Advantages and limitations.

Advantages:

- Provides a reconnaissance level method to develop bathymetric mapping.
- No specialized positioning equipment or training required.
- Visual range intersection proved particularly useful during emergency scour reconnaissance on the Mississippi and Missouri Rivers during Summer 1993 flooding.

Limitations:

- Accuracy is limited. All drawings depicting these surveys should caution users concerning the approximate nature of the data and warn against their use in design or construction.
- Survey data from visually controlled surveys are normally plotted in either plan or profile format, and should not be presented at a larger scale than that used to control the survey.

VISUAL RANGE INTERSECTION
Equipment Sources

- ***No specialized equipment is required***

5.12 Equipment sources

C. Equipment sources.

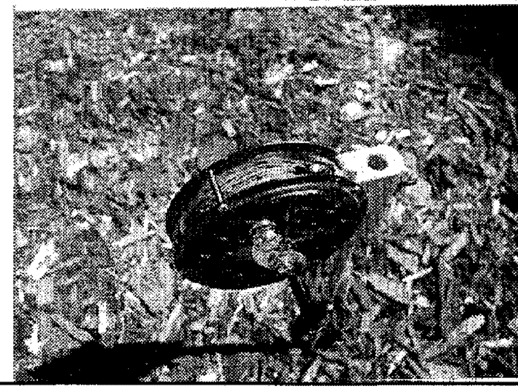
1. No specialized equipment is required for visual range positioning.

V. TAG LINE SURVEY

TAG LINE SURVEY
Theory and Operation

- *Cable marked at pre-set interval and strung across the channel*
- *Boat can be anchored to cable or positioned at a marker using motor*
- *Depth measurements based on probing or sonar*
- *Multiple cross sections provides an intersecting grid*

5.13a Theory and operation



5.13b Tag line

A. Theory and operation.

1. A tag line is a cable marked at pre-set intervals and strung across the channel to provide lateral position. Historically, tag lines have been used extensively in stream-gaging work.

2. In slower moving waters the boat can be anchored to the tag line and maneuvered across the channel. In faster moving waters, the boat motor must be used to position the boat at each marker along the tag line.

3. Depth measurements can be based on physical probing or sonar instruments.

4. Surveying multiple cross sections provides a grid of data points.

TAG LINE SURVEY
Advantages/limitations

- *Advantages*
  - *provides quantitative positioning information*
  - *is a simple, direct method*
- *Limitations*
  - *maximum channel width < 300 m*
  - *can be time consuming at low flows*
  - *can be dangerous at high flows*

5.14 Advantages and limitations

B. Advantages and limitations.

Advantages:

- A tag line survey provides quantitative positioning information when working from a boat.
- The procedure is a simple and direct method for distance measurement.

Limitations:

- The practical maximum distance for a tag line survey is about 300 m. Stringing a tag line over longer distances can be done, but is difficult due to current drag on the tag line at longer distances.
- Can be time-consuming, even at low flows, and is difficult and potentially dangerous at high flows.

TAG LINE SURVEY
Equipment Sources

- *Stream gaging equipment suppliers (Teledyne Gurley, Scientific Instruments, etc)*
- *Low-cost option is a low-stretch rope marked at regular intervals*

5.15 Equipment sources

C. Equipment sources.

1. Tag line equipment is available from stream gaging equipment suppliers, including Teledyne Gurley, Troy, New York (518-272-6300) and Scientific Instruments, Inc., Milwaukee, Wisconsin (414-263-1600).

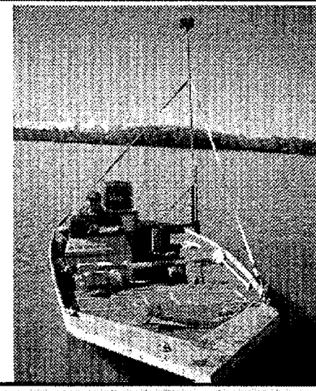
2. A low cost alternative that may be adequate for many applications is low-stretch rope marked at regular intervals.

VI. SIMPLE RANGE-AZIMUTH

SIMPLE RANGE-AZIMUTH
Theory and Operation

- *Total station using range-azimuth survey (intersection of distance and angular measurement)*
- *Prism can be mounted to probe, float or boat*
- *Voice communication used to coordinate sounding with position information*
- *Completed with 2-3 person crew*

5.16 Theory and operation



5.17 Prism pole on boat

A. Theory and operation.

1. Standard land-surveying techniques using a total station and range-azimuth surveying can be used to accurately map a scour hole or channel reach. Range-azimuth positioning involves the intersection of an angular and distance observation, normally generated from the same shore-based reference station.

2. A typical application might involve probing a scour hole from a boat, with a prism attached to the probe. The next level of sophistication might involve a paper-chart sonar, marking points on the chart every time the total station operator has a fix on the boat.

3. Two-way voice communication is used from the boat to the total station to coordinate the vertical depth measurements with the horizontal position measurements.

4. Other survey techniques, such as range-range and/or triangulation intersection methods involving two (or more) shore stations, could also be employed; however, range-azimuth techniques are suitable for scour monitoring work and can be completed with a minimum size survey crew (typically a two- or three-person crew).

SIMPLE RANGE-AZIMUTH
Advantages/limitations

- *Advantages*
  - *common technology*
  - *accurate, repeatable information*
  - *no specialized equipment required*
- *Limitations*
  - *large survey tedious and difficult if current strong*
  - *repeated shore setups may be required*
  - *overbank flooding limits shore setup sites*

5.18 Advantages and limitations

B. Advantages and limitations.

Advantages:

- Implements surveying technology that highway personnel are familar with.
- Provides accurate, repeatable location information.
- No specialized positioning equipment required, other than standard survey equipment.

Limitations:

- A large survey involving many data points can be tedious and difficult if the current is strong.
- Repeated shore station setups may be needed to get data at every pier.
- Flood conditions with overbank flow may complicate locating feasible shore station setup locations.

SIMPLE RANGE-AZIMUTH
Equipment Sources

- ***No specialized positioning equipment required, other than a conventional total station survey instrument***

5.19 Equipment sources

C. Equipment sources.

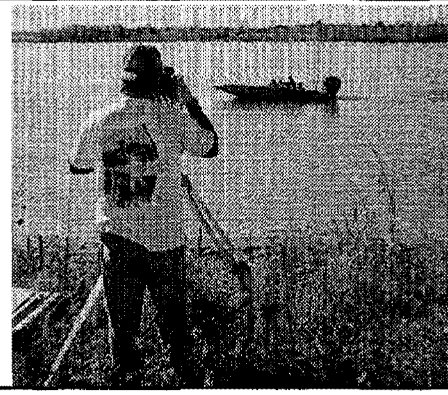
1. No specialized positioning equipment is required, other than a conventional land survey total station.

VII. AUTOMATED RANGE-AZIMUTH

AUTOMATED RANGE-AZIMUTH
Theory and Operation

- *Automated range-azimuth system linked with a sonar to provide continuous x-y-z logging*
- *Manual tracking of boat with right/left indicator to guide helmsman*
- *Fan-head laser eliminates manual tracking*
- *Data points collected automatically at defined interval*
- *Data reduction possibilities*

5.20 Theory and operation



5.21 Hydrographic surveying

A. Theory and operation.

1. Hydrographic surveying equipment involves an automated range-azimuth system linked with a sonar to provide continuous logging of x-y-z positional data.

2. One type of hydrographic survey system involves manual tracking of the boat by the shore station operator, with a left-right indicator in the boat to guide the boat driver on a pre-defined course.

3. Another type of system uses a fan-head laser EDM, eliminating the need for manually tracking the boat.

4. Data points are collected automatically at a defined interval (eg. every 15 m).

5. The logged x-y-z data can be downloaded and imported into any 3-dimensional mapping program for analysis and plotting (e.g., Surfer for Windows by Golden Software, Inc.).

6. Alternatively, Coastal Oceanographics HYPACK program provides an integrated software package for hydrographic survey design, data collection and post-processing. The program supports many different positioning (navigation) systems and echo sounders, and some positioning systems have been specifically designed around HYPACK.

AUTOMATED RANGE-AZIMUTH
Advantages/limitations

- *Advantages*
  - *fast, efficient method*
  - *crew size 2-3*
- *Limitations*
  - *repeated shore setups may be required*
  - *overbank flooding limits shore setup sites*

5.22 Advantages and limitations

B. Advantages and limitations.

Advantages:

- Fast, efficient method to collect data.
- Can be completed with a crew of 2-3 people.

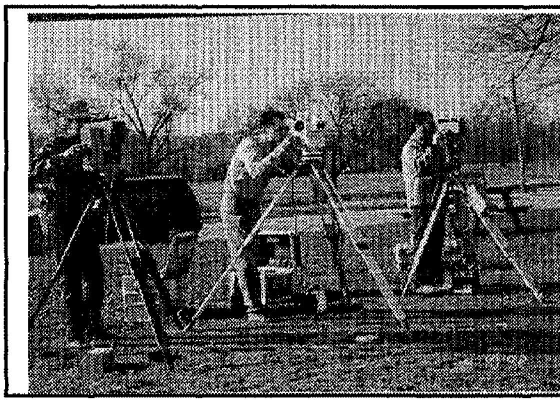
Limitations:

- Repeated shore station setups may be needed to get data at every pier.
- Flood conditions wide overbank flow may complicate locating feasible shore station setup locations.

AUTOMATED RANGE-AZIMUTH
Equipment Sources

- *Innerspace Technology, Inc.*
- *Laser Technology, Inc.*
- *MDL*
- *Odom*

5.23 Equipment sources



5.24 Hydrographic survey equipment (left to right: Odom, Innerspace, Laser Technology)

C. Equipment sources.

1. Innerspace Technology, Inc., Waldwick, New Jersey (201-447-0398).

2. Laser Technology, Inc., Denver, Colorado (303-649-1000).

3. Measurement Devices Limited, Houston, Texas (713 558-7745).

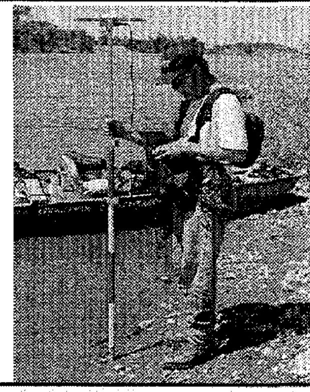
4. Odom Hydrographic Systems, Inc., Baton Rouge, Louisiana (504 769-3051).

VIII. GLOBAL-POSITIONING SYSTEMS

GLOBAL POSITIONING SYSTEMS
Theory and Operation

- *GPS is a DOD satellite-based navigation system*
- *GPS receiver is a range measurement device*
- *Two operating modes*
  - *absolute*
  - *differential (compensates for DOD error)*

5.25 Theory and operation



5.26 GPS equipment

A. Theory and operation.

1. The Navigation Satellite Timing and Ranging (NAVSTAR) GPS is a passive, satellite-based, navigation system operated and maintained by the Department of Defense. Its primary mission is to provide passive global positioning/navigation for land-, air, and sea-based strategic and tactical forces.

2. A GPS receiver is simply a range measurement device: distances are measured between the receiver point and the satellites, and the position is determined from the intersections of the range vectors.

3. There are basically two general operating modes from which GPS - derived positions can be obtained: Absolute Positioning and Differential Positioning. Differential positioning compensates for the error intentionally introduced by the DOD to reduce the utility of GPS to hostile users.

GLOBAL POSITIONING SYSTEMS
Absolute Positioning

- *Passive, real-time navigation mode*
- *Ranges to satellites observed by single GPS receiver*
- *+/- 100 m accuracy*

5.27 Absolute positioning

4. Absolute positioning - The most common military and civil (i.e., commercial) application of GPS is "absolute point positioning". When operating in this passive, real time navigation mode, ranges to NAVSTAR satellites are observed by a single receiver positioned on a point for which a position is desired. This receiver may be positioned to be stationary over a point or in motion.

5. As a result of DOD signal degradation, the accuracy of absolute positioning is ±100 m. This can be compensated for by hours long setup times, but this is not practical for hydrographic survey work.

GLOBAL POSITIONING SYSTEMS
Differential Positioning

- *Measures differences in coordinates between two GPS receivers*
- *Each receiver simultaneously observing/measuring satellites*
- *Centimeter accuracy possible*

5.28 Differential positioning

6. Differential GPS positioning - Differential positioning is simply a process of measuring the differences in coordinates between two receiver points, each of which is simultaneously observing/ measuring satellite code ranges and/or carrier phases from the NAVSTAR GPS constellation. The process actually involves the measurement of the

difference in ranges between the satellites and two or more ground observing points.

7. One GPS station is the "base station" at a position whose coordinates are known. Otherwise, the differential correction can be made using the U.S. Coast Guard system, or commercial systems (e.g., Omnistar, Differential Corrections, Inc.).

8. The resultant accuracy of these coordinate differences is extremely high, usually less than the meter level for code phase observations and approaching a level less than a centimeter for carrier phase tracking.

GLOBAL POSITIONING SYSTEMS
Theory and Operation (cont)

- ***GPS systems can be useful in scour work; however, do not operate under a bridge***
- ***Can be used to range-azimuth systems to locate end points or instrument setups***
- ***Ongoing research***

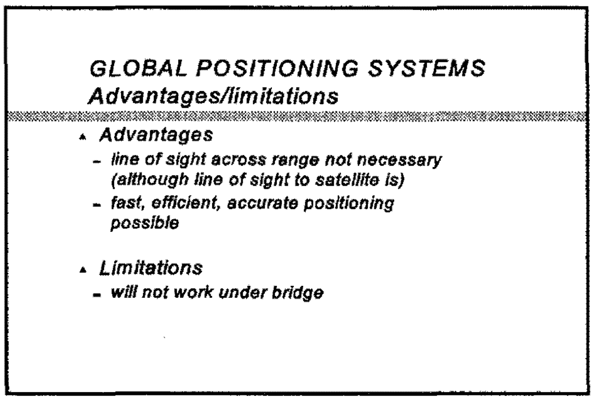
5.29 GPS in bridge scour work

9. GPS systems can be quite useful; however, they will not operate under a bridge where the satellite transmission is blocked.

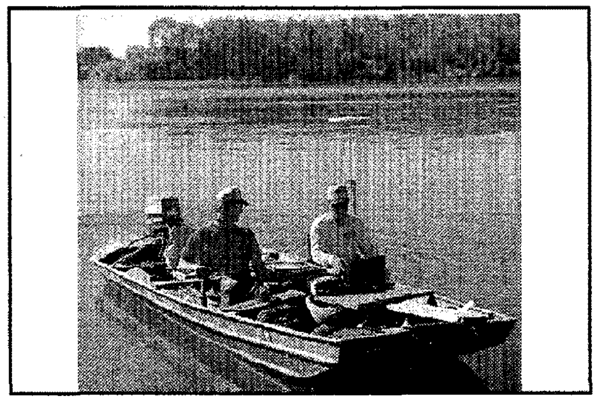
10. The integration of GPS with range-azimuth systems can be useful in bridge scour work (e.g., using GPS to locate range line end points when mapping a channel reach, or to quickly locate multiple range-azimuth instrument setups required for surveying a bridge with many piers).

11. Ongoing research is investigating other ways to effectively integrate GPS in bridge scour inspections, including a Small Business Innovative Research project to link differential GPS with an inertial navigation system to allow tracking under the bridge and then quick recovery of the satellite.

12. A brief overview of GPS technology is provided in the document "Applications of GPS Surveying and Other Positioning Needs in Departments of Transportation" (National Cooperative Highway Research Program, Synthesis 258, 1998).



5.30 Advantages and limitations



5.31

B. Advantages and limitations.

Advantages:

- Line of sight across a range line not necessary, although line of sight to the satellite is.
- Fast, efficient, accurate positioning information available.

Limitations:

- Will not work under a bridge.

GLOBAL POSITIONING SYSTEMS
Equipment Sources

- *Land survey equipment suppliers*
- *Del Norte Technology*
- *Ross Laboratories*
- *Trimble Navigation*
- *Ashtech*

- *Omnistar*
- *DCI*

5.32 Equipment sources

C. Equipment sources.

GPS Receivers

1. Land survey equipment suppliers.

2. Del Norte Technology, Inc., Euless, Texas, (817-267-3541).

3. Ross Laboratories, Inc., Seattle, Washington (206-324-3950),

4. Trimble Navigation, Sunnyvale, California (800-827-8000).

5. Ashtech, Sunnyvale, California (408-524-1400).

Differential Correction Services

6. US Coast Guard Maritime Differential GPS Service (www.navcen.uscg.mil/dgps/default.htm).

7. Omnistar, John E. Chance and Associates, Inc., Houston, Texas (800-854-3287).

8. Differential Corrections, Inc., Cupertino, California (800-446-0015)

NOTES:

LESSON 5

POSITIONING SYSTEMS

PART 2 - DEMONSTRATION

I. HAND-HELD LASER DISTANCE METERS

A. Briefly overview the hand-held survey laser, and the Bushnell laser rangefinder.

B. Application and use

1. Hand-held survey laser devices are essentially a hand-held total station with the ability to rapidly measure range, azimuth and inclination. Laser rangefinders only measure range.

2. Hand-held laser devices allow for reflectorless, one-person operation.

3. Hand-held lasers could be used to track a boat along a visual range, or to position a portable sonar transducer float.

C. Demonstration

P5.1 Hand-held laser

II. AUTOMATED RANGE AZIMUTH SYSTEM

A. Briefly overview the Laser Technology LaserCom hydrographic survey system.

B. Practical aspects of mobilization and application.

1. Rental is expensive ($3500/mo.±) and purchase of a system (not including boat and motor) is approximately $30,000.

2. Boats and motors as small as 4 m and 10 hp are useable in a confined calm environments, 5.5 m and 40 hp are many times a more appropriate minimum.

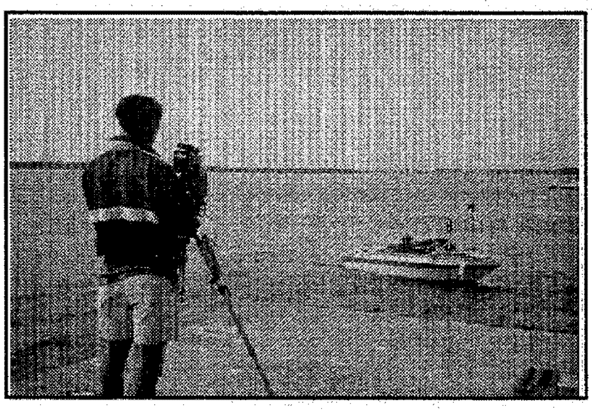
3. Boat launching facilities are needed within a reasonable distance.

4. The shore total station needs to have good topography for a set up as it is usually in use for a considerable period of time tracking the boat.

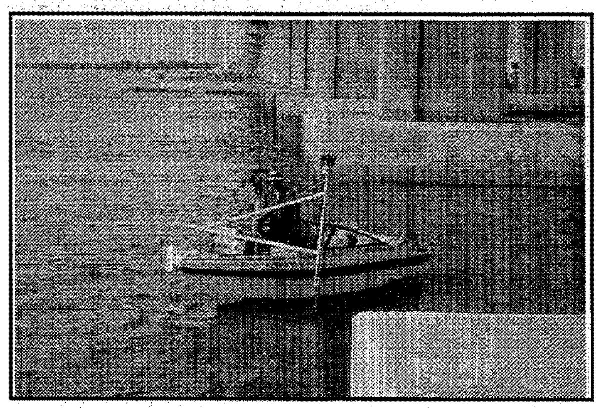
5. Line of sight between the boat/target and the shore total station needs to be of sufficient distance to allow tracking of the boat moving at up to 16 km/hr.

C. Equipment demonstration

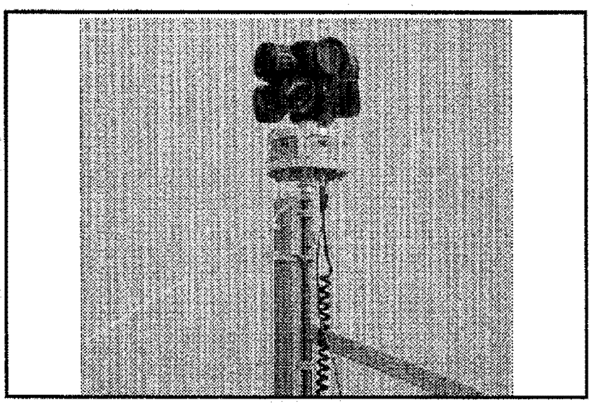
1. Laser Technology LaserCom and HYPACK software (Coastal Oceanographics, Inc.)



P5.2 LaserCom System



P5.3 Boat with prism



P5.4 Prism

III. DATA REDUCTION

A. Depth sounding combined with positioning information results in an X-Y-Z file of coordinate information. Evaluation of this information is most effective if a bathymetric map is produced.

B. A variety of topographic/contouring programs are available for reduction of this type of coordinate data.

C. The demonstration uses Surfer for Windows by Golden Software, Inc., which retails for about $500.00.

LESSON 6

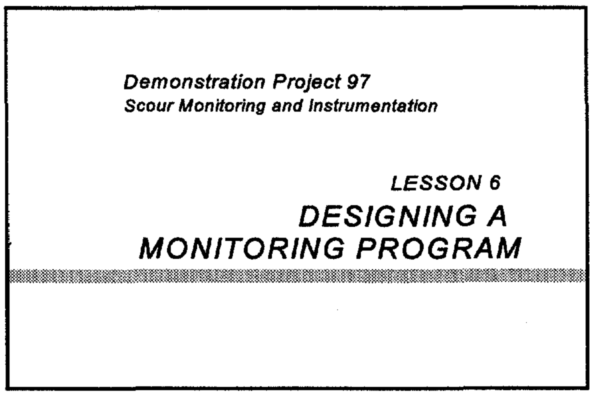
DESIGNING A MONITORING PROGRAM

OVERVIEW: Method of Instruction: Lecture

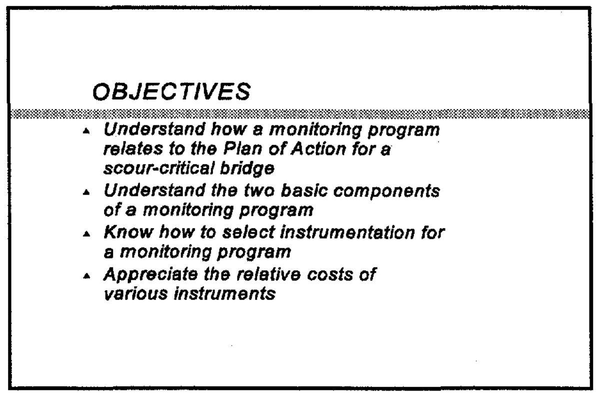
Lesson Length: 60 minutes

Resources:

Lesson Outline
Slides
HEC-18, Chapters 5 and 7



6.0 Lesson Title



6.1 Objectives

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

1. **Understand** how a monitoring program relates to the Plan of Action for a scour-critical bridge.

2. **Understand** the two basic components of a monitoring program (scour measurements and bridge closure instructions).

3. **Know** how to select instrumentation for a monitoring program.

4. **Appreciate** the relative costs of various instruments that might be part of a monitoring program.

LESSON 6

DESIGNING A MONITORING SYSTEM

I. RELATIONSHIP OF SCOUR MONITORING PROGRAM TO PLAN OF ACTION

II. WHAT IS A MONITORING PROGRAM?

III. SCOUR MEASUREMENT CONCEPTS

IV. SELECTING INSTRUMENTATION

V. BRIDGE CLOSURE INSTRUCTIONS

VI. OTHER FACTORS

VII. RELATIVE COSTS OF INSTRUMENTS

VIII. SAMPLE MONITORING PLAN

LESSON 6

DESIGNING A MONITORING PROGRAM

I. RELATIONSHIP OF SCOUR MONITORING PROGRAM TO PLAN OF ACTION

MONITORING PROGRAM AND THE PLAN OF ACTION

- *Scour critical bridges require a plan of action*
- *Plan of action includes:*
  - *Instructions regarding type and frequency of inspections*
  - *Schedule for design and construction of scour countermeasures*
- *A scour monitoring program will facilitate the inspection requirement of a plan of action*

6.2 Plan of action

A. Bridges identified as scour critical, either by office or field review, require development of a Plan of Action. As discussed in Lesson 2, the Plan of Action describes the countermeasures (hydraulic, structural, or monitoring) that will be employed for the identified scour critical condition.

B. As discussed in Lesson 2, a Plan of Action includes:

- instructions regarding the type and frequency of inspections to be made at the bridge, particularly in regard to monitoring the performance and closing of the bridge.

- Schedule for the design and construction of scour countermeasures.

C. A "Scour Monitoring Program" will facilitate the inspection requirement of a "Plan of Action" by describing both the scour measurements and the bridge closure instructions.

MONITORING AS A COUNTERMEASURE

- *Scour monitoring can also be used as a countermeasure; however, monitoring does not fix the scour problem.*
- *Monitoring can provide an early warning, allowing implementation of other countermeasures.*
- *Monitoring can be used alone, or in conjunction with other countermeasures.*

6.3 Monitoring as a countermeasure

D. Monitoring can also be used as a countermeasure in the Plan of Action; however, the use of monitoring does not fix the scour problem and the bridge would still be considered scour critical.

E. A monitoring program allows time to implement hydraulic or structural countermeasures and/or to close the bridge.

F. Monitoring can be used alone, or in conjunction with other countermeasures.

II. WHAT IS A MONITORING PROGRAM?

> *MONITORING PROGRAMS*
>
> - *Two primary components:*
>   - *Scour measurements*
>   - *Specific bridge closure instructions*
> - *Note that a monitoring program includes more than just scour measurements*
> - *A well-designed monitoring program can be a cost-effective countermeasure*

6.4 Monitoring programs

A. A monitoring program includes

(1) Scour measurements that facilitate early identification of potential scour problems, and

(2) Specific instructions describing precisely what must be done if a bridge is at risk due to scour, including a bridge closure plan, detour plan, etc.

B. Note that a monitoring program, as defined, involves more than instrumentation (i.e., scour measurement and specific guidance on bridge closure procedures).

C. A well-designed monitoring program can be a very cost-effective countermeasure; however, if bridge safety relies only on a monitoring program, and that program is not effective (for whatever reason), potential liability could be incurred in the event of a bridge failure.

III. SCOUR MEASUREMENT CONCEPTS

SCOUR MEASUREMENT CONCEPTS

- *Regular versus intermittent measurements*
- *Emergency mobilization*
- *Instrument type versus measurement type*
- *Areal coverage considerations*
- *"Where and when" for portable/geophysical instruments*
- *Toolbox approach*

6.5 Scour measurements

A. Scour measurements may be taken on a regular basis (e.g., hourly) or an intermittent basis (e.g., during and after major flooding) depending on the perceived risk of a scour-related problem. At the 2-year inspection cycle soundings are required for all bridges. Scour measurements may also be part of:

- Underwater inspection at 5-year intervals for all bridges
- Inspection during a flood, preferably near peak flow conditions
- Periodic inspections after major floods
- Ongoing scour measurement program

B. During major flooding, emergency mobilization may be necessary to collect scour data. Plans and procedures for emergency mobilization should be included in a monitoring plan.

C. Generally speaking, fixed instrumentation is used for regular scour measurements; portable instruments are typically used for intermittent or emergency measurements, and; geophysical instruments are used for forensic measurements (that is, evaluating what happened during a previous flow event).

D. The areal coverage required in a monitoring program depends in part on when there is a need to differentiate the type of scour occurring (local scour, contraction scour or degradation, any one of which will produce bed lowering at a bridge pier or abutment).

1. If it is sufficient to know only that the channel bottom is dropping, limited measurements around the pier or abutment will be sufficient.

2. If it is necessary to distinguish local scour from contraction scour or degradation, more extensive areal surveys will be required. This consideration then influences the type of positioning system required.

3. Differentiating the type of scour might be necessary to evaluate analytical predictions by scour formulas or to understand the cause of an observed scour problem in order to design appropriate countermeasures.

E. Intermittent measurement by portable or geophysical instrumentation should include specific guidance on when and where measurement should be taken (e.g., sound bed elevation in front of Piers 1 and 2 during floods exceeding elevation 100.00).

F. No one instrument or type of instrument will be adequate for every bridge or every monitoring program, but rather a "toolbox" approach should be used where a variety of instruments and methods are available to implement a monitoring program.

IV. SELECTING INSTRUMENTATION

SELECTING INSTRUMENTATION

- *Instrument selection will depend on site conditions and instrument applicability*
- *Engineering judgment required*
- *Monitoring programs will typically involve a mix of instrumentation*

6.6 Selection factors

A. Selection of the appropriate instrumentation for a monitoring program will depend on site conditions (streambed composition, bridge height off water surface, flow depth and velocity, etc.) and operational limitations of specific instrumentation (e.g., as related to high sediment transport, debris, ice, specialized training necessary to operate a piece of equipment, etc.).

B. Engineering judgment will always be required in designing instrument specifications to maximize the scour information collected within the given resources.

1. For fixed instrumentation, the number and location of instruments will have to be defined, as it may not be practical or cost effective to instrument every pier and abutment.

2. For portable instrumentation, the frequency of data collection and the detail and accuracy required will have to be defined, as it may not be possible to complete detailed bathymetric surveys at every pier or abutment during every inspection.

C. Most monitoring programs will involve a mix of fixed, portable and geophysical instruments to collect data in the most efficient manner possible. Furthermore, portable instrumentation should be used to ground-truth fixed instrumentation to insure accurate results and to evaluate potential shifting of the location of maximum scour.

INSTRUMENTATION SUMMARY

Instrument Category	Advantages	Limitations
Fixed	Continuous monitoring, low operational cost, easy to use	Max scour not at instrument location, maintenance/loss
Portable	Point measurement or complete mapping, use at many bridges	Labor intensive, special platforms often required
Geophysical	Forensic investigation	Specialized training required, labor intensive
Positioning	Necessary for portable and geophysical	-----

6.7a Instrument summary

FIXED INSTRUMENTATION

	Best Application	Advantages	Disadvantages
Sonar	Coastal regions	Off-the-shelf components, Time-history	Debris, high sediment air entrainment
Sounding Rods	Coarse-bed channels	Simple, mechanical device	Unsupported length, binding, augering
Magnetic Sliding Collar	Fine-bed channels	Simple, mechanical device	Unsupported length, binding, debris
Float Out	Empheral channels	Lower cost, ease of installation	Battery life

6.7b Instrument summary (cont)

PORTABLE INSTRUMENTATION

	Best Application	Advantages	Limitations
Physical Probes	Small bridges and channels	Simple technology	Accuracy, high flow application
Sonar	Large bridges and channels	Point data or complete mapping, accurate	High flow application

6.7c Instrument summary (cont)

POSITIONING SYSTEMS

	Best Application	Advantages	Limitations
Approximate Methods	Recon or inspection	No special training	Accuracy
Visual Range Intersection	Recon level mapping	No special training	Accuracy
Tag Line Survey	Small channels	Simple method, quantitative	Labor intensive, high flow
Simple Range Azimuth (R-A)	Small areal surveys	Common, accurate	Labor intensive
Automated R-A	Large areal surveys	Fast/efficient accurate	Shore station requirements
GPS	Support of R-A	Fast/accurate	Not under bridge

6.7d Instrument summary (cont)

D. Based on the information presented during this demonstration project, Slides 6.7a-d summarize the different types of instruments available for scour measurement and monitoring, their "best" application, and their advantages and disadvantages.

V. BRIDGE CLOSURE INSTRUCTIONS

BRIDGE CLOSURE INSTRUCTIONS

- *Scour critical elevation required to define the need for further action*
- *Specific closure instructions necessary*
- *Responsibilities must be assigned*
- *Instructions must detail how the closure will physically be accomplished*

6.8 Bridge closure

A. A scour-critical elevation should be provided to inspection personnel for each pier to be monitored so that a clear indication is possible defining the need for further action.

B. Specific bridge closure instructions will insure that appropriate action is taken, if monitoring determines that a bridge is at risk.

C. Instructions must detail responsibilities, including

- Who makes measurements?
- Who is notified?
- Who decides to close a bridge?
- Who has authority to re-open a bridge?
- Who establishes and marks detour routes?
- Who talks to the media?

D. Instructions should also detail how the closure is physically accomplished to keep traffic off the bridge until such time that it is safe for traffic to pass (barricades, etc.).

VI. OTHER FACTORS

A. If monitoring is used as a countermeasure, this needs to be clearly communicated to the Inspectors and/or maintenance personnel.

OTHER FACTORS

- *If monitoring used as a countermeasure, this must be communicated to inspectors and/or maintenance personnel*
- *Bridge inspectors should receive training and instruction in scour inspection*

6.9 Other factors

B. 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.

2. The bridge inspector should identify conditions indicative of potential problems with scour and stream stability (e.g., eroding bankline, missing riprap, sagging).

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.

VII. RELATIVE COSTS OF INSTRUMENTS

RELATIVE COST OF INSTRUMENTS

- *Cost information necessary to design a monitoring program*
- *Cost includes instrument cost, installation cost (fixed instruments) and operational cost*

6.10 Relative costs

A. To design a monitoring program it is beneficial to know the relative costs of various instruments.

B. Slides 6.11a-c provides some general guidelines on various instrument costs.

FIXED INSTRUMENTATION

	Instrument cost	Installation Cost	Operation Cost
Sonar	$4,000-5,000	5 person-days	1-hr per site visit
Sounding Rods	$5,000-7,500	5 person-days	1-hr per site visit
Magnetic Sliding Collar	$2,500-5,000	5 person-days	1-hr per site visit
Float out	$3,000 + $500/float out	varies	1-hr per site visit

6.11a Fixed instrument costs

PORTABLE INSTRUMENTATION

	Instrument Cost	Operation Cost	Operation Crew Size
Physical Probes (lead line, sounding pole, etc)	<$1,000	Varies	minimum of 2 for safety
Sonar	Fish-finder $500 Survey-grade $15,000 +	Varies	minimum of 2 for safety

6.11b Portable instrument costs

POSITIONING SYSTEMS

	Instrument Cost	Operation Cost	Crew Size
Approximate Methods	Neglible	Varies	1-2
Visual Range Intersection	Neglible	Varies	1-2
Tag Line Survey	<$1,000	Varies	1-2
Simple Range Azimuth (R-A)	$10,000 +	Varies	2-3
Automated R-A	$20,000 +	Varies	2-3
GPS	$10,000 +	Varies	2-3

6.11c Positioning system costs

VIII. SAMPLE MONITORING PLAN

Notes:

LESSON 7

COURSE SUMMARY AND CRITIQUE

OVERVIEW: Method of Instruction: Lecture

Lesson Length: 30 minutes

Resources: Lesson Outline

OBJECTIVES: The objectives of this lesson are to provide any closing remarks, to briefly discuss the optional one and one-half days in Demonstration Project 97, and to receive any suggestions for changes or improvements from the Participants.

LESSON 7

COURSE SUMMARY AND CRITIQUE

I. COURSE SUMMARY

II. OPTIONAL FIELD DEMONSTRATION

III. COURSE CRITIQUE

LESSON 7

COURSE SUMMARY AND CRITIQUE

I. COURSE SUMMARY

A. The purpose of Demonstration Project 97 was to promote the use of new and innovative equipment for scour measurement and monitoring. The four major categories of equipment are: fixed, portable, geophysical and positioning systems.

B. The equipment specifically selected for demonstration was, generally speaking, available off-the-shelf and has been field-tested and used for bridge scour measurement and/or monitoring. Any or all of this equipment has a place in the "toolbox" that each state may develop for scour measurement.

C. How you equip your "toolbox" will depend in part on your bridge population, and scour problems. Some of the equipment demonstrated is quite expensive and may be more effectively implemented by outside hire.

D. One-of-kind and other new and innovative equipment was discussed, but not demonstrated. However, as research and development continues, some of this equipment may become viable and readily available, and should at that time be considered for your "toolbox."

II. OPTIONAL FIELD DEMONSTRATION

A. An optional field demonstration (up to one and one-half days) may be scheduled on a state-by-state basis. The field demonstration does not necessarily need to be scheduled immediately following Lecture 7, and may be requested at a later date after having already completed the core one and one-half day course.

B. Possibilities for the field demonstration include a visit to a bridge where scour instrumentation can be demonstrated. This may include a bridge where a fixed instrument has previously been installed, or any bridge where demonstration of portable, geophysical or positioning equipment could be completed.

C. In addition to the equipment used in the workshop based demonstrations, the FHWA survey boat is available and could be scheduled for field demonstration. The boat is a 25-ft Boston Whaler with twin 200 horsepower outboard engines and can be outfitted with a variety of portable or geophysical instrumentation.

D. Other possibilities for field demonstration include other recent research efforts by the USGS and others, such as the remote control boat, the articulated arm, etc, or one-of-kind, proprietary equipment such as the ScourVision system.

E. Field demonstration may also be used to actually install a fixed instrument at a bridge.

F. Any other ideas or possibilities for field demonstration may be proposed for consideration by FHWA (contact Mr. Tom Krylowski, 202-366-6771 or Mr. Jorge Pagan, 202-366-4604).

III. COURSE CRITIQUE

A. Any suggestions for changes or improvements are appreciated.

B. If you become aware of any other new or innovative instrumentation in the future, please contact FHWA or one of the Instructors.

NOTES: