PILOT STUDY FOR COLLECTION OF BRIDGE-SCOUR DATA

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CONVERSION FACTORS

Inch-pound units used in this report may be converted to SI (International System) units by using the following conversion factors:

Multiply	*By*	*To obtain*
cubic foot	0.02832	cubic meter
cubic foot per second	0.02832	cubic meter per second
degree (°)	0.01745	radian
foot	0.3048	meter
foot	304.8	millimeter
foot per foot	1.000	meter per meter
foot per second	0.3048	meter per second
foot per second squared	0.3048	meter per second squared
foot squared per second	0.0929	meter squared per second
inch	25.40	millimeter
mile	1.609	kilometer
pound	0.4535	kilogram

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ABSTRACT

Scour around bridges is a serious problem on many rivers; bridge failure commonly is attributed to undermining of piers or abutments by scour. A pilot study was made at four bridge sites in Colorado to develop and test guidelines for collecting scour data onsite during high flows. These guidelines potentially could be used to conduct bridge-scour studies or to establish a nationwide bridge-scour data-collection program in conjunction with normal high-flow measurements. The methods tested are compatible with equipment and procedures commonly used in the U.S. Geological Survey streamflow-gaging program. Thirteen scour-prediction equations were evaluated using data collected during this study. Two alternative approaches for future, proposed scour studies are indicated. The type of approach selected would depend on the objectives of the scour study and the flow conditions in the study area.

INTRODUCTION

Scour around bridges is a serious problem on many rivers (Neill, 1973). Many bridge failures recorded in the past can be attributed directly to the undermining of piers or abutments by scour (Laursen and Toch, 1953). Total scour around bridges in alluvial channels can occur as a result of a combination of three types of interrelated phenomena: local scour, general scour that may be increased by contractions of the stream channel, and degradation of a channel (Simons and Senturk, 1977). Local scour is caused by local disturbances in the flow, such as vortices and eddies around obstructions as described by Shen and others (1969). These disturbances result in an abrupt decrease in bed elevation near the obstruction. Examples are scour at the base of piers, abutments, and similar obstructions. General scour from flood flow or contractions is caused by increased velocities and sediment transport in the contracted width. Examples are scour in stream channels that are contracted by natural channel constrictions, constrictions between bridge abutments, and spur dikes. Degradation or aggradation of a stream channel occurs throughout a relatively long reach and time because of permanent changes in channel controls, such as sediment supply, dams, and changes in river form. Degradation or aggradation in stream reaches generally are slow processes and are not considered in this study.

The problem with estimating scour in river systems is that the scour commonly is a combination of these three types of scour processes. When scour has more than one source, it is difficult to evaluate and separate the scour into components. A bridge failure because of scour around the pier does not necessarily indicate that local scour was the cause. At a site during lower flood flow, scour may be entirely from local scour; but as flows increase, general scour because of bridge contractions may predominate. Hopkins and others (1980) concluded that the majority of total scour comes from bridge contractions and that local pier scour is less than 20 percent of the total scour depth when the bridge is a constriction within the channel. Shen and others (1969), Neill (1970), and Simons and Senturk (1977) provide detailed descriptions of the scour process as observed in the laboratory.

When designing bridges across rivers, the magnitude of potential scour around piers and scour through the bridge constriction during flood flows is estimated. Therefore, considerable research has been done on scour. Karaki and Haynie (1963) have compiled a bibliography of references made from 1863 to 1963 on scour research and studies. Since 1963, additional research has been done. Until now (1985), most research about bridge scour has been done in laboratory flumes (Laursen and Toch, 1953; Komura, 1966; Shen and others, 1969; Shen, 1971; Jain and Fischer, 1980) that provide analytical or empirical scour-prediction equations. Many of these flume studies have been made using clear water (no sediment supply), and only a few studies have been made about the difference between clear-water scour and scour from sediment-transporting flow (National Cooperative Highway Research Program, 1970). Shen and others (1969) and Shen (1975) indicate that a major problem in predicting prototype scour from laboratory studies is that of determining model scale. Numerous scour-prediction equations have been published (Anderson, 1974; Hopkins and others, 1980), but predicted scour depths are quite varied, especially when the equations are applied outside the range of conditions for which they were developed.

Existing methods for estimating scour are based on laboratory tests but have received minimal onsite verification because of a lack of measured scour data. This lack of verification is due partially to the difficulty in predicting the occurrence of high flows so data can be collected and because of the hazards of collecting data during high flows. The National Cooperative Highway Research Program (1970) indicates that the hazards of collecting scour data during floods could be decreased by selecting sites in stream or river reaches downstream from dams where flows are controlled and where there would be minimal debris. Dams affect the sediment balance for some time and distance downstream and generally result in degradation of the channel bed and banks. Williams and Wolman (1984) describe hydraulic and sediment changes downstream from 21 dams constructed on alluvial rivers. The advantages and disadvantages of scour studies in these stream reaches need to be evaluated.

The importance of collecting scour data has been recognized as necessary to improve the understanding and predictive capabilities of estimating scour depths; however, there is no nationwide program for the compilation of onsite scour data (Culbertson and others, 1967). Several onsite scour studies have been made. Lane and Boreland (1954) present streambed change elevation data for the Rio Grande at San Marcial, N. Mex. Culbertson and others (1967) present several case histories of scour at bridge sites that were used to improve U.S. Geological Survey bridge-site reports. Neill (1970) summarizes scour data from several sources and presents recommendations on collecting and recording scour data. Shen (1975) reviewed California Highway Department files and compiled scour data near bridge piers for 12 sites and found only a limited quantity of data available. Shen indicates one of the main reasons for the limited quantity of scour data is that engineers are not aware of the data needed for bridge-pier scour studies. Norman (1975) measured and presented data about general scour at bridge crossings and local scour around bridge piers at nine bridge sites in Alaska. He found that the maneuverability and mobility of a boat and a boat-mounted fathometer[1] were desirable assets for determining bed forms, measuring cross sections, and collecting data adjacent to piers. However, because of the dangers of working during high flows and the debris that commonly collects on piers, he found it preferable to use sounding weights for determining streambed elevations along the upstream and downstream sides of the bridges. Norman (1975) indicated that prediction equations do not include all of the channel situations that can be found at bridge sites. Blodgett (1984) described the effects of bridge piers on streamflow and channel geometry at 23 sites in California, Idaho, and Utah. Blodgett found that general scour may be greater than local scour.

The National Cooperative Highway Research Program (1970), Shen (1975), Hopkins and others (1980), and Jones (1984), recommended the first priority in scour research be given to onsite measurements and measurements using simple approaches on piers that have standard geometry. The goals of scour research would be to evaluate the accuracy of existing scour-prediction equations, to be compatible with laboratory results, and to establish a more definitive relation between scour and its influencing factors. High flows occur on some streams in the United States every year, and the scour data that could be collected from these flows would be instrumental in developing improved techniques for estimating scour depths or for verifying existing methods. A consideration in site selection is that floods may seldom occur at sites that have permanently mounted equipment; therefore, it may take many years before data would be obtained.

Purpose and Scope

The primary purpose of this study was to develop and test guidelines for collecting scour data onsite during high flows. The methods tested are compatible with equipment and procedures commonly used in the U.S. Geological Survey streamflow-gaging program. This approach has the advantage that it would benefit from the experience of a large number of personnel who routinely work with flood-measuring equipment in addition to their mobility and the availability of equipment. These guidelines potentially could be used to establish a nationwide program to collect scour data at selected streamflow-gaging stations located at or near bridges. A secondary purpose was to evaluate local scour-prediction equations.

The installation of permanent equipment was not considered as a method of collecting scour data because water-borne debris may destroy the scour sensors, the equipment often does not function properly, or a flood does not occur during the period of study (Norman, 1975; Hopkins and others, 1980). Use of a power boat also was not considered because of the hazards associated with high flows and turbulence of flow near bridges (Norman, 1975).

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[1]Use of brand or trade names in this report is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.

Acknowledgments

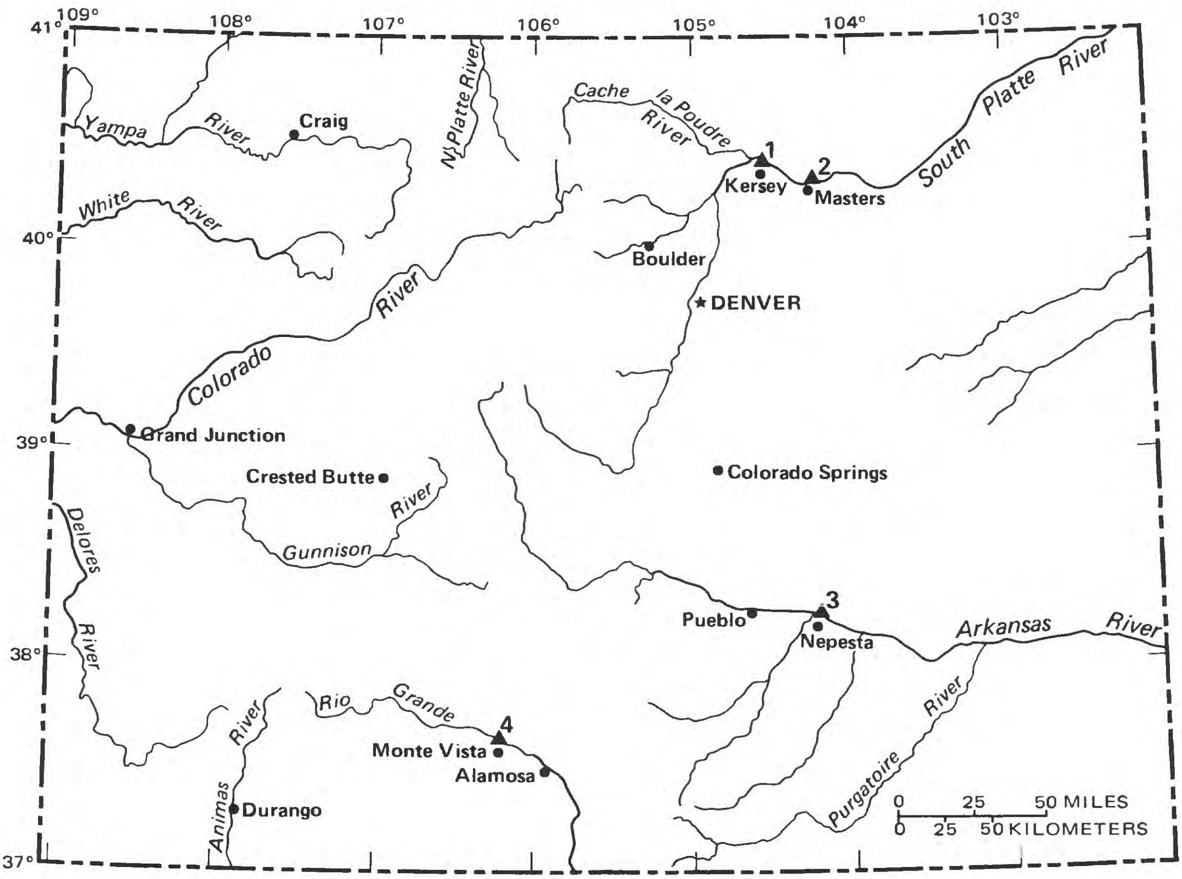
The authors would like to thank Gary C. Johnson of the Colorado Department of Highways for his help in selecting sampling sites and in providing additional information, and Lawrence J. Harrison of the U.S. Federal Highway Administration, Region 8, for providing information on site selection and scour-prediction equations and report review. The authors appreciate the assistance of Gary L. Schaefer of the U.S. Soil Conservation Service, Lawrence E. Tunnel of the U.S. National Weather Service, and Jack Truby of the Colorado Divison of Disaster Emergency Services for their information on the timing and magnitude of runoff. The authors also appreciate the input on project planning and technical support from Roy E. Trent, U.S. Federal Highway Administration.

DESCRIPTION OF STUDY SITES

Four sites were selected for the collection of bridge-scour data. All four sites are located at or near streamflow-gaging stations in Colorado. The four streamflow-gaging stations associated with the selected bridge sites are: (1) 06754000, South Platte River near Kersey; (2) 06756995, South Platte River at Masters; (3) 07117000, Arkansas River near Nepesta; and (4) 08221500, Rio Grande at Monte Vista. These sites primarily were selected because, during the winter of 1983-84, record or near-record snowpacks existed in the headwaters of the rivers; they had a great potential for significant runoff and possibly scour at bridges; and the bridges did not appear to contract the main channel flow. The locations of the study sites are shown in figure 1. Photographs of the bridge sites are shown in figures 2A-D. Pier and bridge dimensions were obtained from State and County highway plans and from onsite measurement.

South Platte River near Kersey

Site 1, South Platte River near Kersey, is located on State Highway 37, 1.9 miles north of Kersey. The streamflow-gaging station that was established during 1901 is located on the left bank, downstream from the bridge, and has a strip-chart recorder. The gage is operated by the Colorado Division of Water Resources. The bridge was built during 1958 and is 663 feet long and has 12 concrete piers spaced 51 feet apart. The piers are 1.7 feet wide and 27.2 feet long and are pointed on the ends as shown in figure 3A. The piers are at a 60-degree angle to the bridge roadway. During high flow, the piers are aligned with most of the flow, but during low flows, the piers are at an angle to the flow. This angle is approximately 0 degrees starting at the left bank and increases to about 50 degrees on the right bank. The majority of the flow is along the left side of the river. The flow usually is contained between the left bank and the 10th pier from the left bank. A small channel, separated from the main channel by a large island, merges with the main channel about 100 feet upstream from the bridge along the right bank. During low flows, there are sandbars along the right side of the river downstream from the bridge. Also, there are three small islands approximately 250 feet downstream from the bridge. The South Platte River is a sand-bed channel at this location. The range of discharge during data collection was 1,240 to



EXPLANATION

▲1 LOCATION AND SITE NUMBER

Figure 1.--Location of study sites.

Figure 2A.--Cross-stream view of bridge from right bank of South Platte River near Kersey, October 3, 1984. Note debris on piers. Discharge was 1,240 cubic feet per second.

Figure 2B.--Cross-stream view of bridge from right bank of South Platte River at Masters, October 1, 1984. Discharge was 1,570 cubic feet per second.

Figure 2C.--Cross-stream view of bridge from left bank of Arkansas River near Nepesta, May 23, 1984. Discharge was 2,460 cubic feet per second.

Figure 2D.--Cross-stream view of bridge from left bank of Rio Grande at Monte Vista, May 22, 1984. Discharge was 2,200 cubic feet per second.

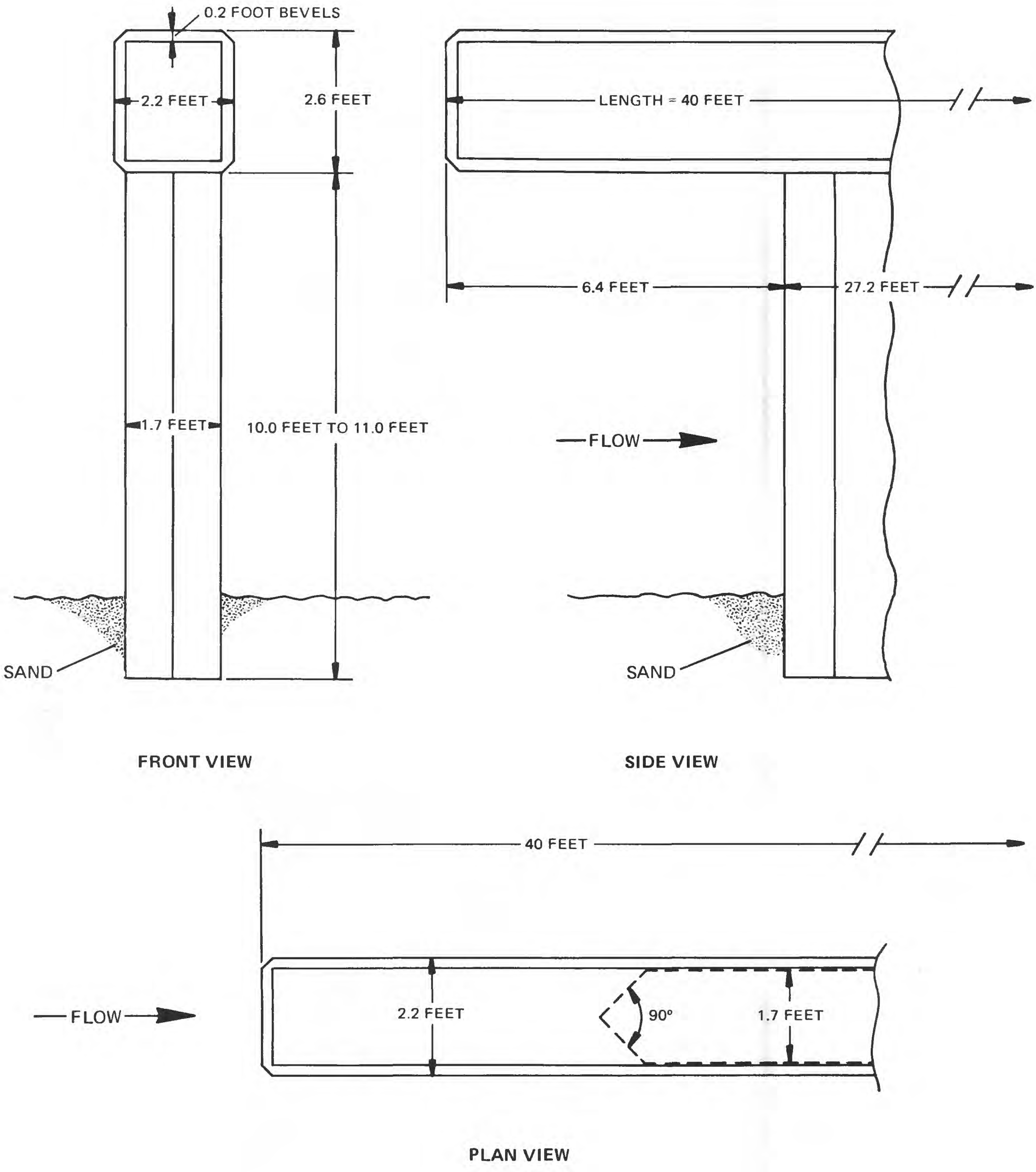


Figure 3A.--Pier, South Platte River near Kersey.

6,630 cubic feet per second. Average velocity in the approach cross section ranged from 2.64 to 5.52 feet per second. Average depth in the approach cross section ranged from 1.95 to 4.83 feet. The maximum peak discharge for the year was 9,550 cubic feet per second on May 17, 1984.

Data collection in the vicinity of the piers at site 1 was difficult because of excessive debris around them. As can be seen in figure 2A, large logs and other debris are piled up against the piers on the left side of the river. This debris made it difficult and sometimes impossible to measure the depth of scour near these piers. Another problem at this site is that the bridge overhangs the upstream edge of the piers by 6.4 feet (fig. 3A). The sounding weight could not be positioned next to the piers; therefore, the cross section was measured along the edge of the bridge instead, and the sounding weight was allowed to drift downstream. Another problem is that the flow is at an angle to the piers along the right bank side of the bridge. This angled flow causes a more complicated scour problem than if the flow was aligned with the piers.

South Platte River at Masters

Site 2, South Platte River at Masters, is located on County Road 87, 1.0 mile north of Masters and U.S. Highway 34. The streamflow-gaging station that was established during 1976 is located on the right bank, downstream from the bridge, and has a strip-chart recorder. The gage is operated by the U.S. Geological Survey. The year the bridge was built is unknown (the authors estimate that the bridge is at least 40 years old). The bridge is 283 feet long and has eight concrete piers spaced 40 feet apart. The piers are 0.95 foot wide and 12 feet long and have a flat surface on the upstream side as shown in figure 3B. The piers are perpendicular to the bridge and are aligned with the flow. The majority of the flow is along the right side of the river. There are two channels flowing into the South Platte River at about 100 feet and 25 feet upstream from the bridge along the right bank. During low flows, there is a sandbar along the left side of the river that extends upstream and downstream from the bridge. The South Platte River is a sand-bed channel at this location. The range of discharge during data collection was 1,450 to 8,010 cubic feet per second. Average velocity in the approach cross section ranged from 2.40 to 4.57 feet per second. Average depth in the approach cross section ranged from 1.87 to 5.85 feet. The maximum peak discharge for the year was 8,220 cubic feet per second on May 18, 1984.

The depth of scour at the first pier and in front of the second pier from the right bank could not be measured because of debris buildup. Also, velocities at the second and third piers from the right bank made it difficult to position the sounding weight in front of these piers. The depth of scour was measured on either side of these piers.

Arkansas River near Nepesta

Site 3, Arkansas River near Nepesta, is located on County Road 613, 0.98 mile north of U.S. Highway 50. The streamflow-gaging station that was established during 1903 is located about 3 miles upstream from the bridge on the

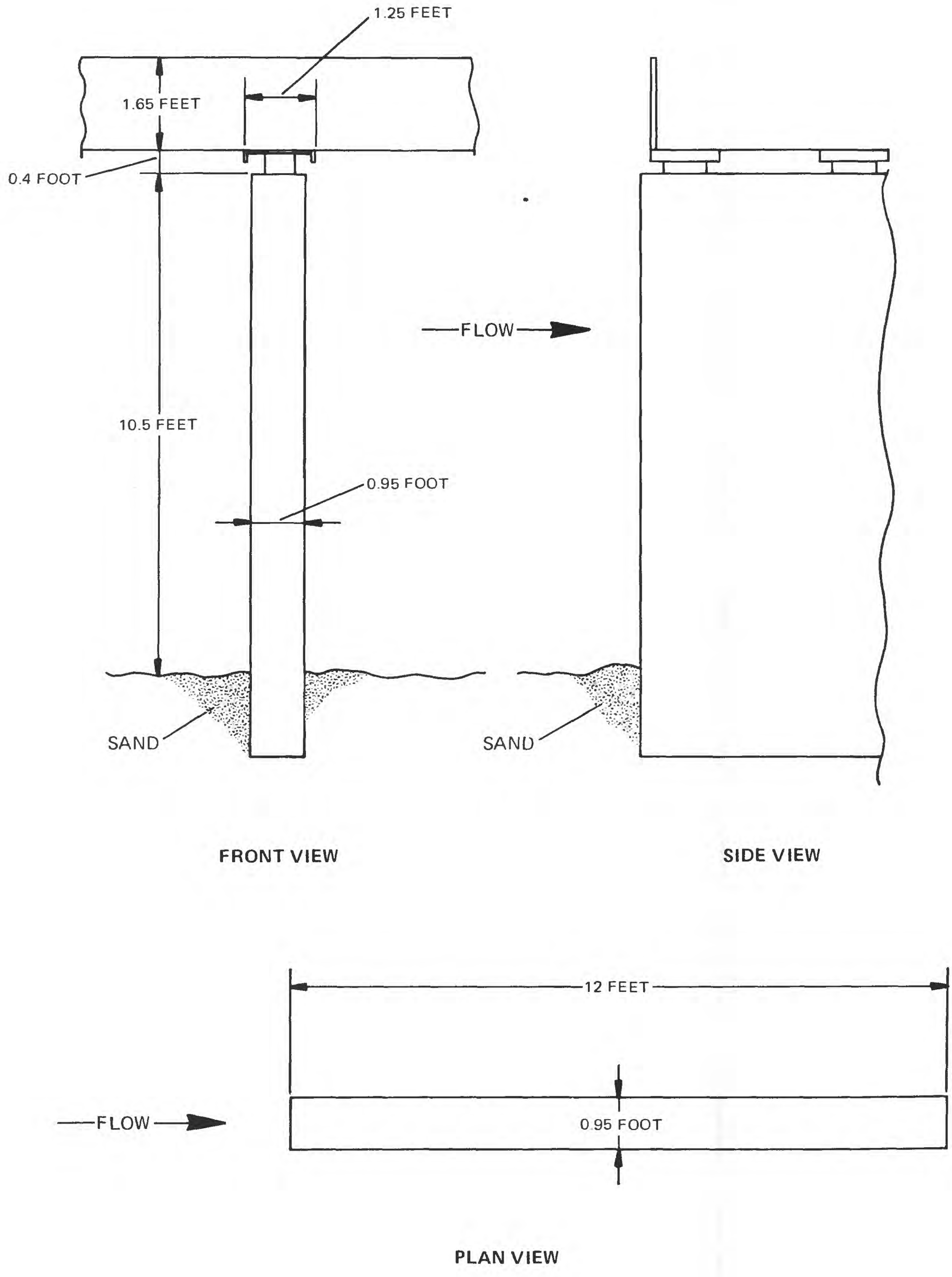


Figure 3B.--Pier, South Platte River at Masters.

right bank and has a strip-chart recorder. The gage is operated by the Colorado Division of Water Resources. The bridge was built during 1905, is 361 feet long, and has three sets of concrete-filled steel cylinder piers spaced 105 feet apart. Each pier is circular, has a 4-foot diameter, and is connected to its pair by a steel web for a total length of 21 feet as shown in figure 3C. About 60 feet upstream from the roadway bridge, there is a railroad bridge that has two piers. This bridge may have an effect on the river scour. The majority of the flow is along the left side of the river. During low flows, there is a sandbar in the middle of the river that extends from upstream of the railroad bridge to downsteam of the roadway bridge. This sandbar is about 140 feet wide at its center. The Arkansas River is a sand-bed channel at this location. The range of discharge during data collection was 363 to 3,690 cubic feet per second. Average velocity in the approach cross section ranged from 1.74 to 4.77 feet per second. Average depth in the approach cross section ranged from 0.80 to 5.30 feet. The maximum peak discharge for the year was 13,600 cubic feet per second on August 22, 1984.

A temporary staff gage was used to determine the fluctuation in river stage each time data were collected at the site. A number of diversions and channel inputs exist upstream from site 3 that made it difficult to correlate the discharge at site 3 to the discharge at the streamflow-gaging station. The center pier had a large quantity of debris that made it difficult to measure the scour depth, but because this pier is located on the sandbar, the scour depth at the pier probably was minor.

Rio Grande at Monte Vista

Site 4, Rio Grande at Monte Vista, is located on U.S. Highway 285, 2 miles north of Monte Vista. The streamflow-gaging station that was established during 1938 is located on the left bank, downstream from the bridge, and has a strip-chart recorder. The gage is operated by the Colorado Division of Water Resources. The bridge was built during 1971 and is 176 feet long and has one concrete pier located in the center of the channel. The pier is 2.0 feet wide at the top and then tapers to 3.25 feet wide at the footing, is 90 feet long, and is pointed on the upstream side as shown in figure 3D. The majority of the flow is along the left side of the river. During low flows, there is a gravelbar along the right bank extending upstream and downstream from the bridge, a part of which is shown in figure 4. Also, there is a gravelbar along the left side of the pier that extends from underneath the bridge to downstream from the bridge. This site was selected because moderate scour previously had been observed. The Rio Grande is a gravel-bed channel at this location. No unusual problems were found when measuring at this site. The range of discharge during data collection was 108 to 2,200 cubic feet per second. The average velocity in the approach cross section ranged from 0.81 to 5.05 feet per second. The average depth in the approach cross section ranged from 1.41 to 4.01 feet. The maximum peak discharge for the year was 3,830 cubic feet per second on May 27, 1984.

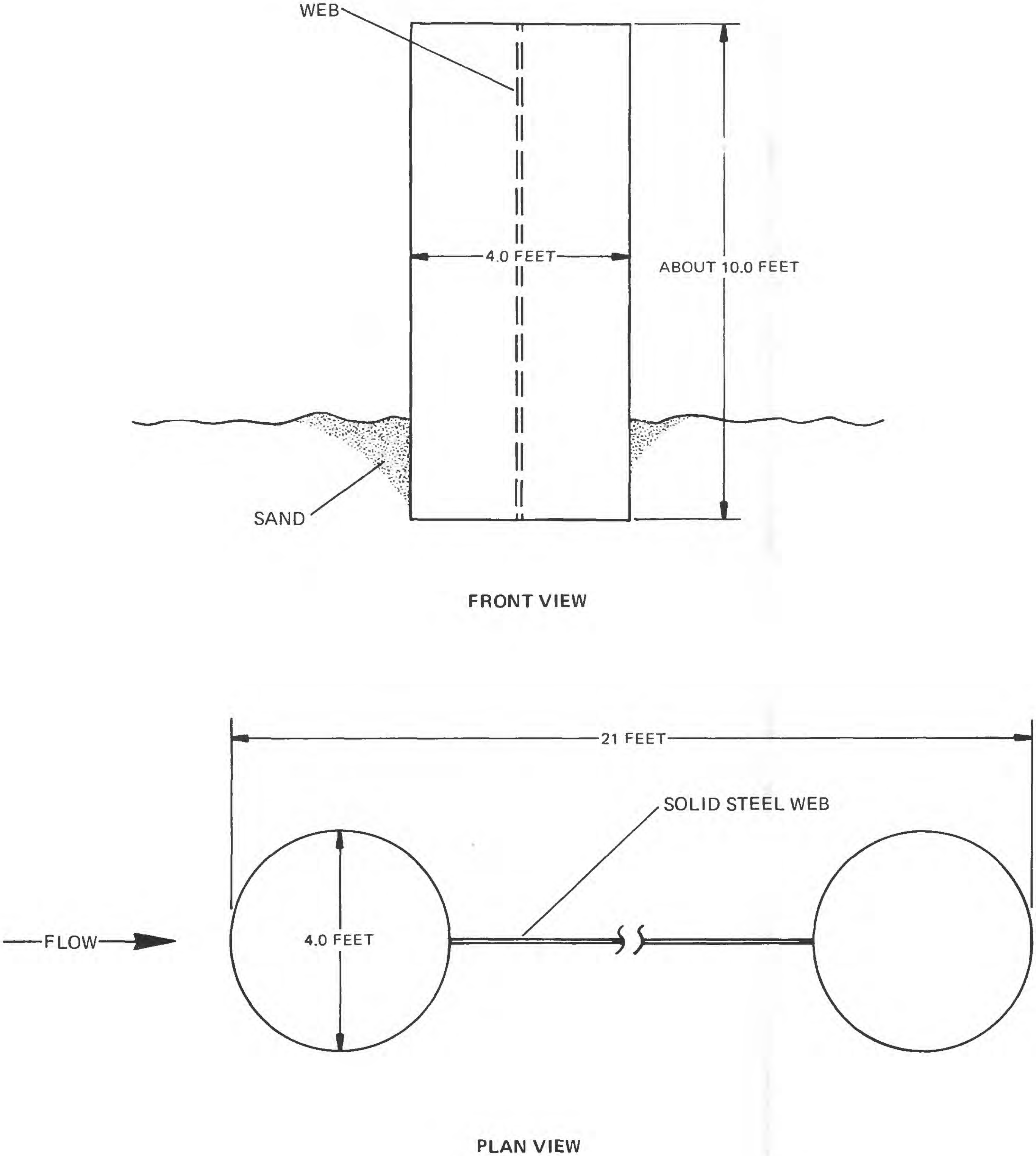


Figure 3C.--Pier, Arkansas River near Nepesta.

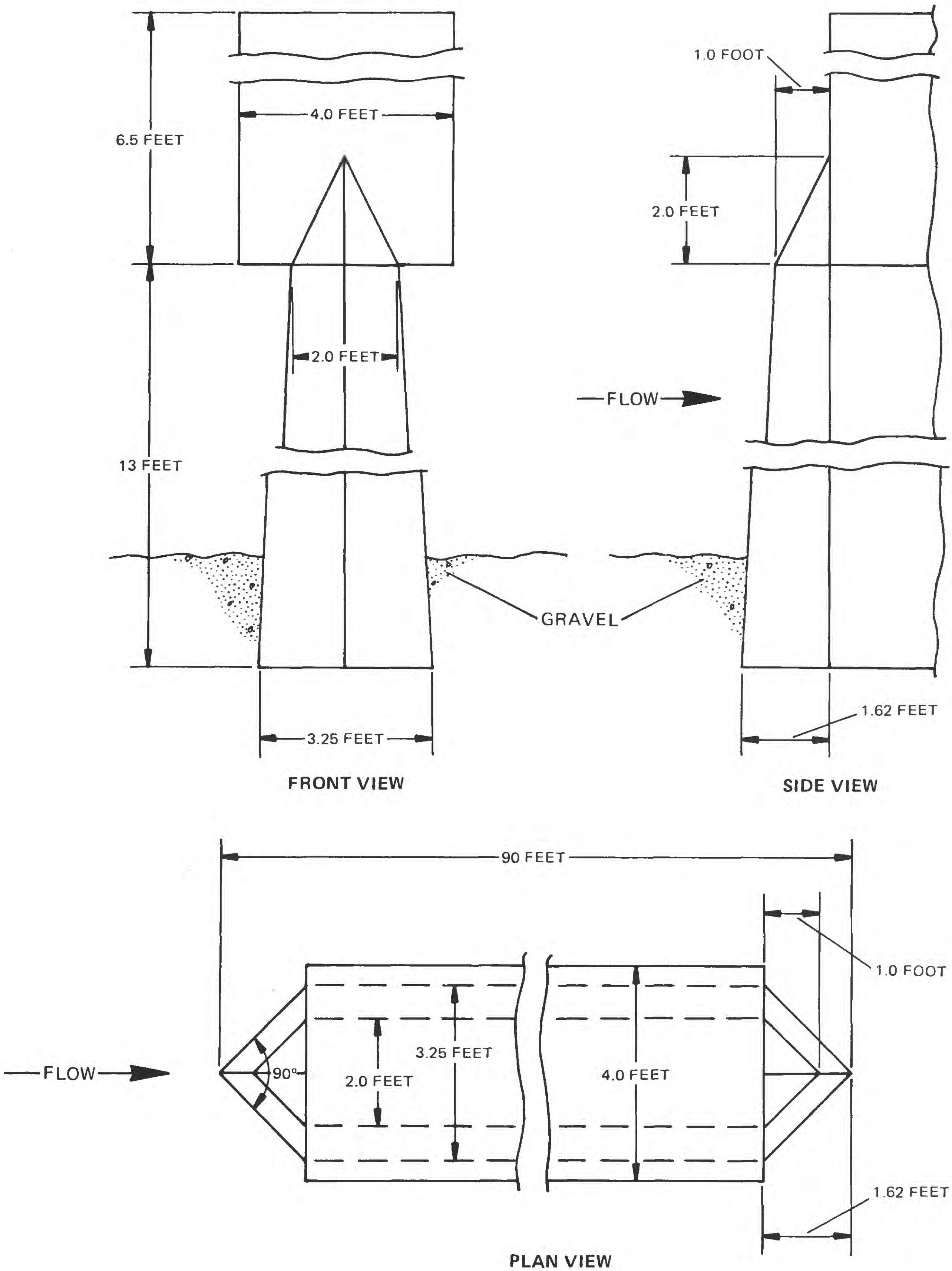


Figure 3D.--Pier, Rio Grande at Monte Vista.

Figure 4.--Cross-stream view from right bank of Rio Grande at Monte Vista, September 25, 1984. Discharge was 108 cubic feet per second.

DATA-COLLECTION METHODS

This section of the report provides a summary of the scour-data sampling program for the four sites in the pilot study. Collection methods, equipment, and summaries of hydraulic and sediment data are presented.

Scour-Data Sampling Program

The sampling program for this pilot study consisted of collecting scour data at each site during the leading edge, peak, and recession periods of the flow. Data collected during each of these flow periods are shown in table 1. Because the study did not begin until late spring, scour data were not collected before the period of peak flows at three of the four selected sites. Instead, scour data were collected at these three sites twice during the recession period. For all four sites, the last measurement was made during the fall during low flows. The low-flow measurement was made to establish bed elevations when sediment transport was minimal. Because of difficulties in predicting when the spring peak flow would occur, the highest flow measured at each site is not necessarily the peak flow for the spring runoff during 1984. A brief discussion of the measurements that were made during the different periods as shown in table 1 follows.

Table 1.--*Data collected during the pilot study*

[X indicates measurements made; dashes indicate no measurement]

Flow Period	Discharge and gage height	Upstream cross section	Down-stream cross section	Scour depth at piers	Velocity near piers	Average approach velocity	Approach cross section	Water-surface profile	Bed-material samples	Bridge geometry	Photo-graphs
Leading edge	X	X	X	X	X	--	--	X	--	--	X
Peak	X	X	X	X	X	--	--	X	X	--	X
Recession	X	X	X	X	X	X	X	X	X	X	X

Cross sections were measured (sounded) at the upstream and downstream sides of each bridge. In addition, the discharge and gage height were measured for each flow period to record channel-bed elevations and corresponding discharge for scour conditions at the upstream and downstream sides of each bridge. Scour depth at the piers was measured for each flow period to determine changes in scour and discharge and to determine the maximum scour that occurred on the sides or upstream side of the piers. Velocity near the piers was measured for each flow period to facilitate the estimation of an average approach velocity, if needed, for the higher flows. According to Shen (1971), as a dune passes a pier, the equilibrium depth of scour decreases as the crest passes and increases as the trough passes. Therefore, maximum scour depth at the pier that had the deepest scour hole for each site was monitored during each visit to the site to determine if the movement of bed material had any effect on the depth of scour.

The average approach velocity and approach cross section were measured only during the recession flow period because no cableways were located upstream from the bridges to enable measurements during high flows. The approach cross section for the recession flow period was used to estimate the average approach velocity and average approach depth for the leading-edge, peak, and recession flows. The approach cross section was surveyed approximately 100 to 200 feet upstream from the bridge where the channel was most representative and accessible. The stability of the approach cross section during high flows was unknown; therefore, the approach cross section was assumed to be stable for all flow conditions.

The water-surface profile in the study reach was measured for each flow condition. If the water-surface profile was measured for many different discharges, a curve might be definable so water-surface profiles would not have to be measured at each visit. Water-surface elevations also were measured at selected intervals upstream and downstream from each bridge to determine if there were any local changes in water-surface elevations at the bridge.

Bed-material samples were collected during the peak and recession flows. Samples were not collected during the leading-edge flow period only because the sediment-sampling equipment was not available before the first measurements. Bed-material samples were collected in the scour holes near piers and at intervals along the cross section on the upstream side of each bridge.

The bridge geometry was measured during the recession flow period when the rivers were wadable. Photographs were taken of each site, including debris around the piers and flow conditions, to have a visual record of each visit. General observations of data-collection procedures, duration of sampling, and data-collection problems also were recorded.

Data-Collection Equipment

Sounding for river depth and velocity were made simultaneously by using standard streamflow-gaging procedures (Rantz and others, 1982). Depth and position in the vertical were measured by suspension of a sounding weight from a cable at high flow or by wading and using a wading rod at low flow. The Price type AA meter was used to measure velocity. Columbus sounding weights of 50 to 100 pounds were used to keep the meter and weight fairly vertical and stationary in the water. A type A-reel mounted on a type A-crane that has a four-wheel base and a boom was used to raise and lower the meter and weight as shown in figure 5A. The only difference from normal streamflow measurement techniques was measuring depth and velocity as near to the pier as possible, whereas measurements usually are avoided in the vicinity of the pier. A tag line was used to determine the distance on the horizontal for any point in the cross section.

Water-surface elevations were measured using standard surveying instruments and techniques (Benson and Dalrymple, 1967). Permanent reference marks were available at each site. Gage datum was maintained for vertical control at all sites except for the Arkansas River near Nepesta, where an arbitrary datum was used. Horizontal control was referenced to magnetic north for all sites. The measurement points along the bridge were marked with paint. River stages were recorded at or near all the sites by automatic recorders. Stage-measuring equipment is described in Rantz and others (1982).

Bed-material samples were collected using samplers appropriate for existing stream velocities. At high flows, streambed and scour-hole sand and small gravel were collected using the US BM-54 bed-material sampler attached to the A-reel and A-crane (Guy and Norman, 1970). The US BM-54 is a 100-pound sampler for use during moderate to high flows that, by spring action, scoops about 6.18×10^{-2} cubic feet of sand or gravel-bed material when it touches the streambed. Samples were obtained for the streambed and scour holes at all sites except the South Platte River near Kersey. At low flow, these bed-material samples were collected at all sites using a locally constructed, hand-held, bed-material sampler, a variation of the drag sampler described by Norman (1975). The top 1 inch of bed material collected using the handheld sampler was discarded because some of the fine material may have washed out. The bed-material samplers are shown in figures 5B and 5C. Analyses of bed-material size were determined using methods described by Guy (1969).

A summary of the collected hydraulic data (discharge, average approach velocity, average approach depth, Froude number, and average surface-water slope) for each of the four sites is presented in table 2. The water-surface profiles indicated there was approximately 0.25 to 0.40 foot of backwater at both South Platte River sites but minimal backwater at the other two sites. The water-surface elevations along the upstream and downstream sides of the bridge generally did not vary by more than several tenths of a foot except for local buildup or drawdown of about 0.5 foot in the vicinity of the piers. A summary of the bed-material sizes for each site is presented in table 3. Any differences in bed-material sizes at a site could be the result of sampling variability, possible armoring, or changes during different flow conditions. Upstream and downstream bridge cross sections and an approach cross section for all sites are shown in figures 6A-C, 7A-C, 8A-C, and 9A-C. The average

Figure 5A.--Type-A crane on a four-wheel base and boom.

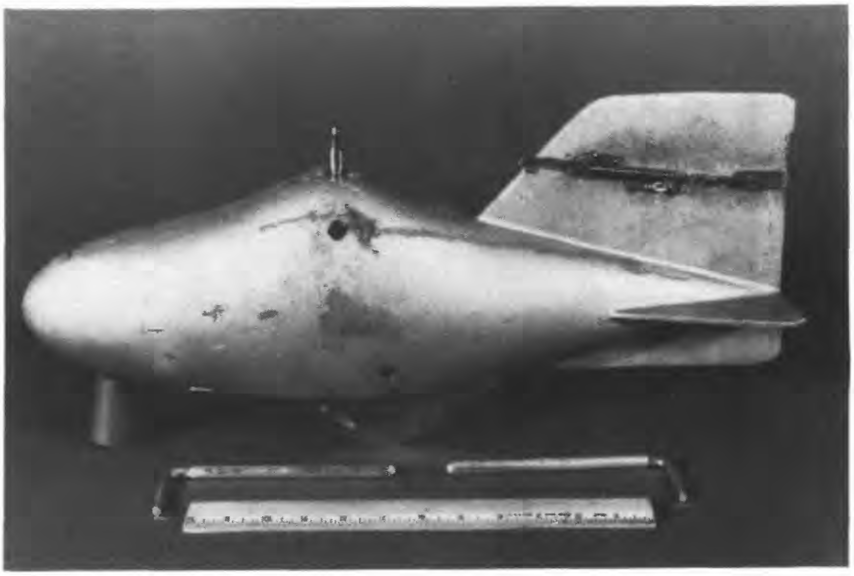


Figure 5B.--Cable-and-reel, spring-driven, rotary-bucket, 100-pound, bed-material sampler, US BM-54.

Figure 5C.--Hand-held bed-material sampler.

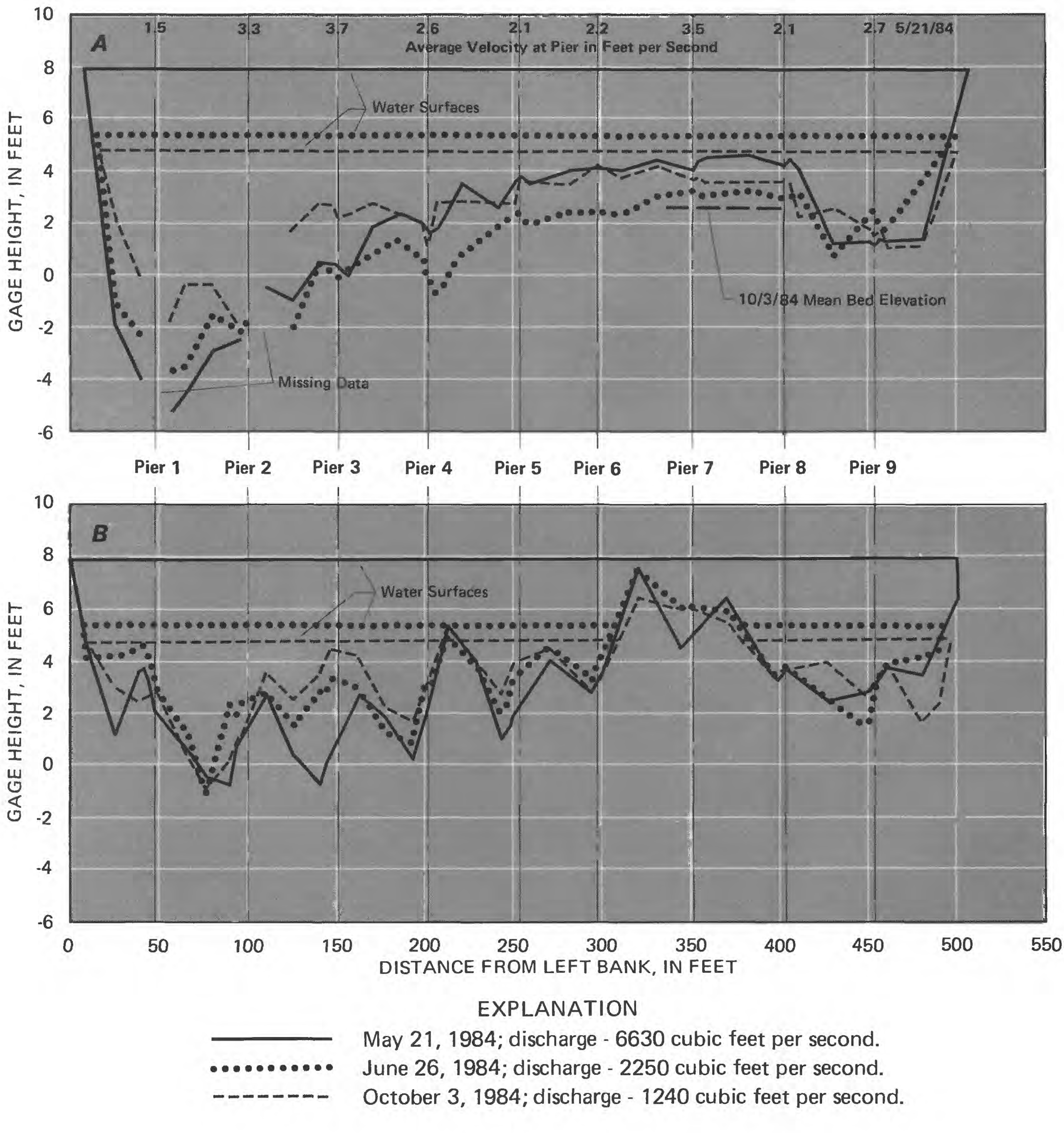


Figure 6.--Cross sections of bridge, South Platte River near Kersey: (A) Upstream; (B) Downstream.

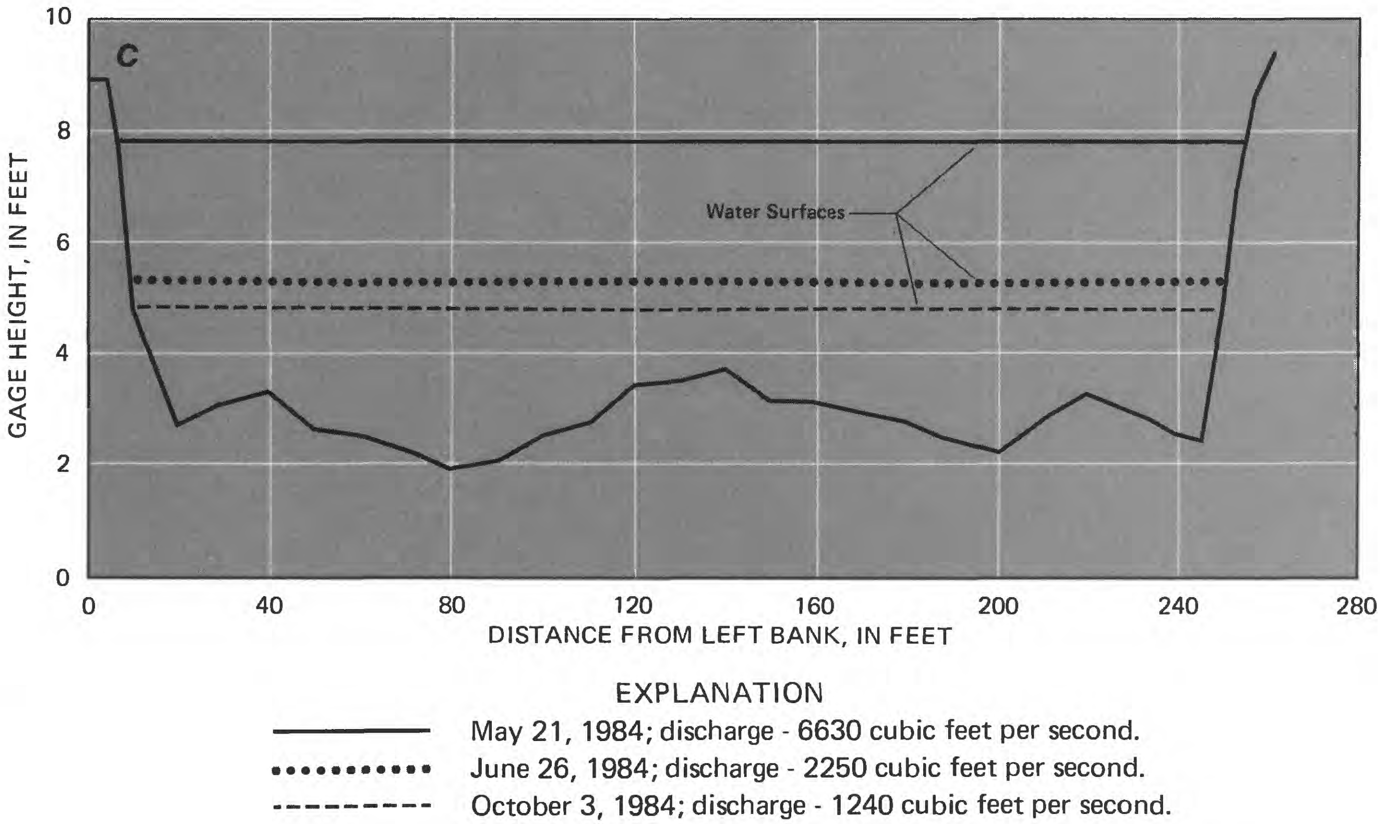


Figure 6(C).--Approach cross section, South Platte River near Kersey.

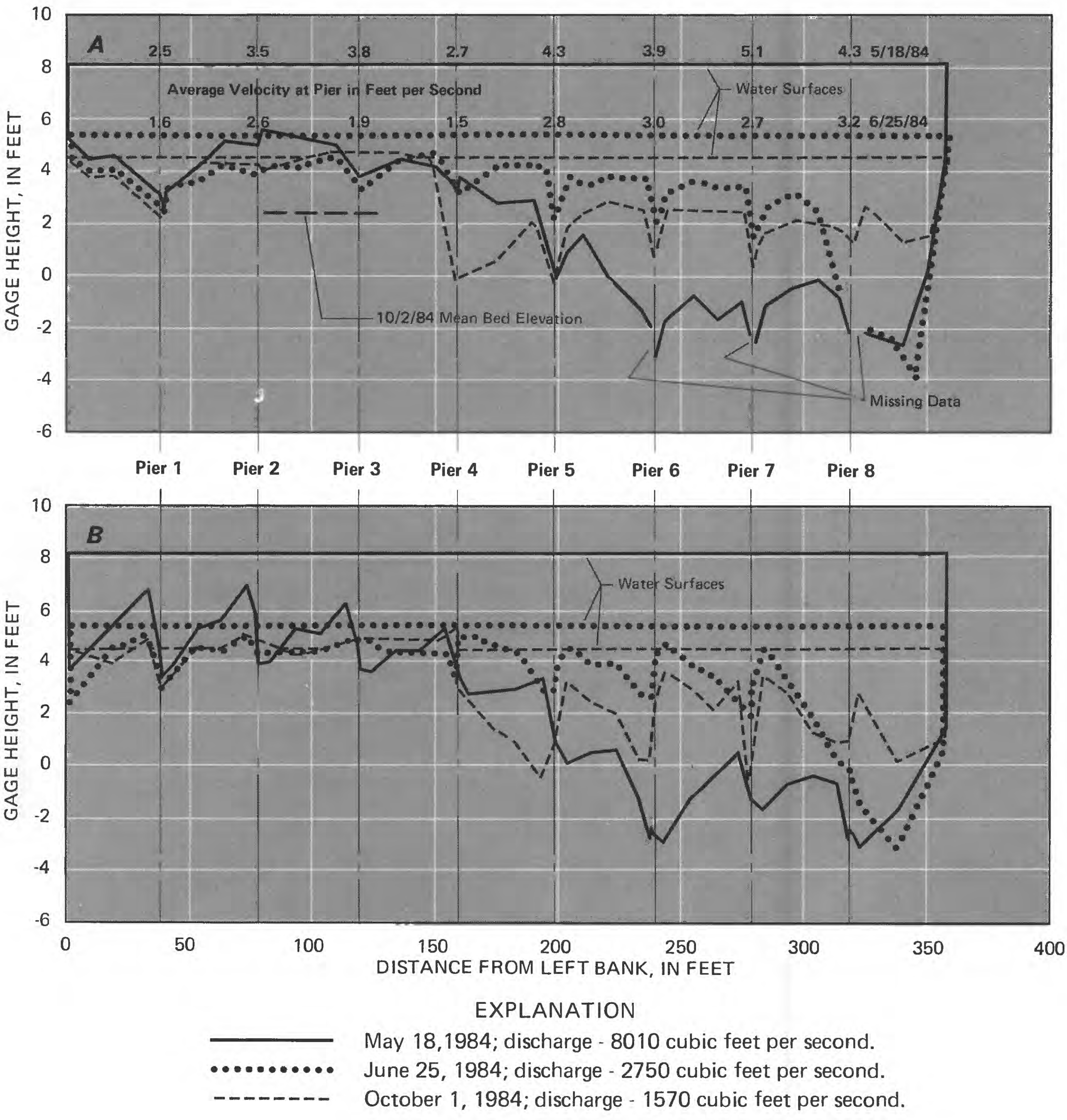
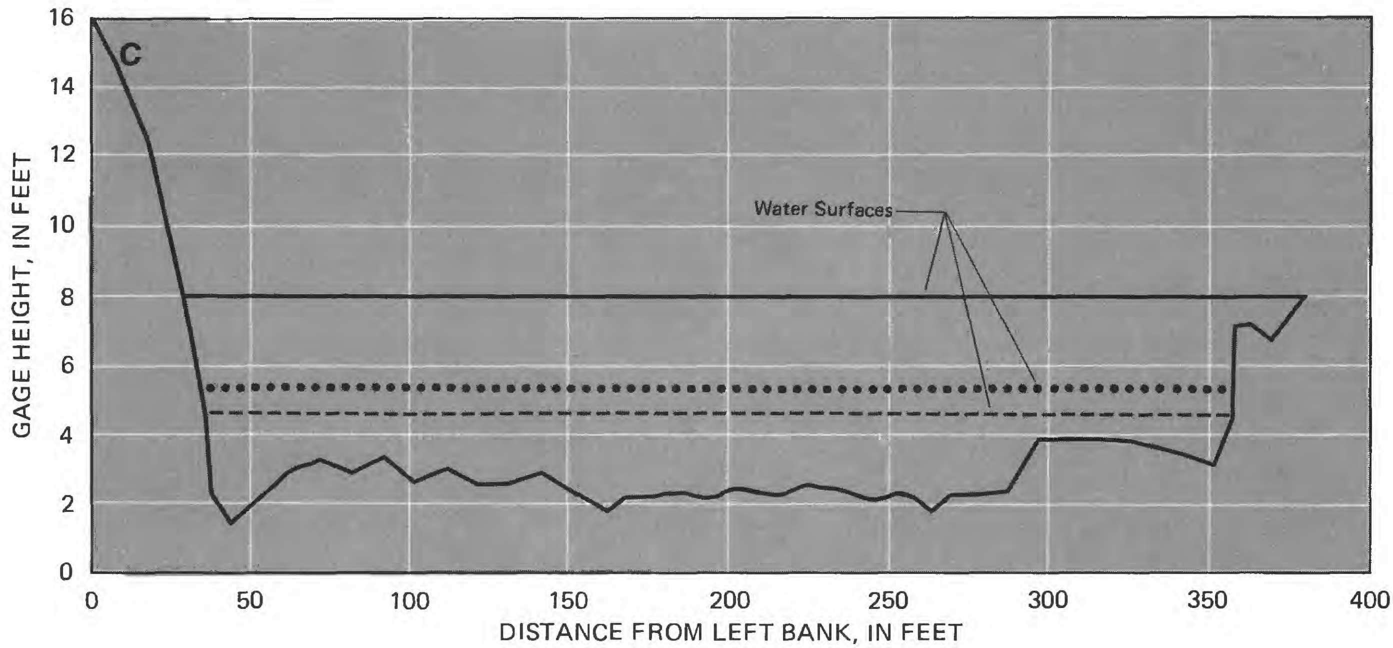


Figure 7.--Cross sections of bridge, South Platte River at Masters: (A) Upstream; (B) Downstream.



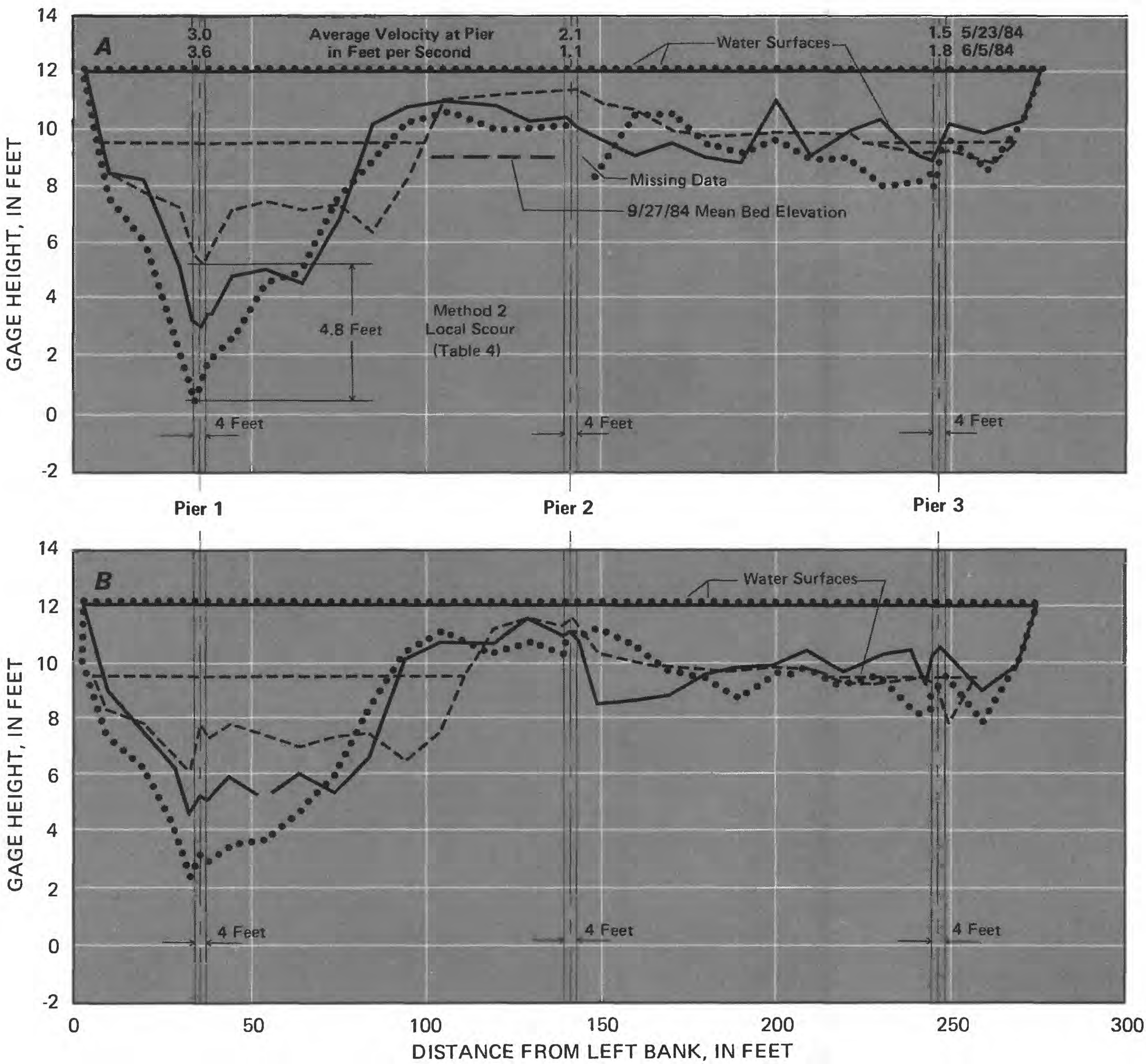
EXPLANATION

——— May 18,1984; discharge - 8010 cubic feet per second.

••••••••••• June 25, 1984; discharge - 2750 cubic feet per second.

-------- October 1, 1984; discharge - 1570 cubic feet per second.

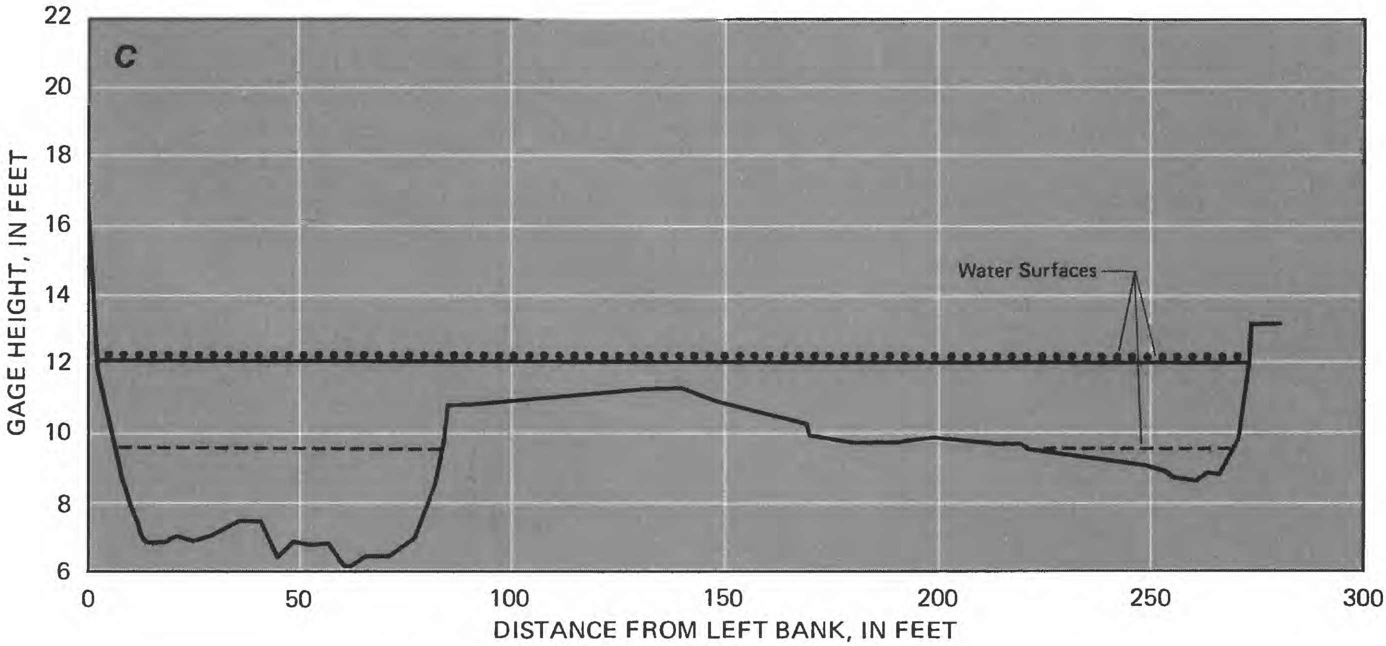
Figure 7(C).--Approach cross section, South Platte River at Masters.



EXPLANATION

————	May 23,1984; discharge - 2460 cubic feet per second.
••••••••••	June 5, 1984; discharge - 3690 cubic feet per second.
--------	September 27, 1984; discharge - 363 cubic feet per second.

Figure 8.--Cross sections of bridge, Arkansas River near Nepesta: (A) Upstream; (B) Downstream.



EXPLANATION

————	May 23,1984; discharge - 2460 cubic feet per second.
••••••••••	June 5, 1984; discharge - 3690 cubic feet per second.
--------	September 27, 1984; discharge - 363 cubic feet per second.

Figure 8(C).--Approach cross section, Arkansas River near Nepesta.

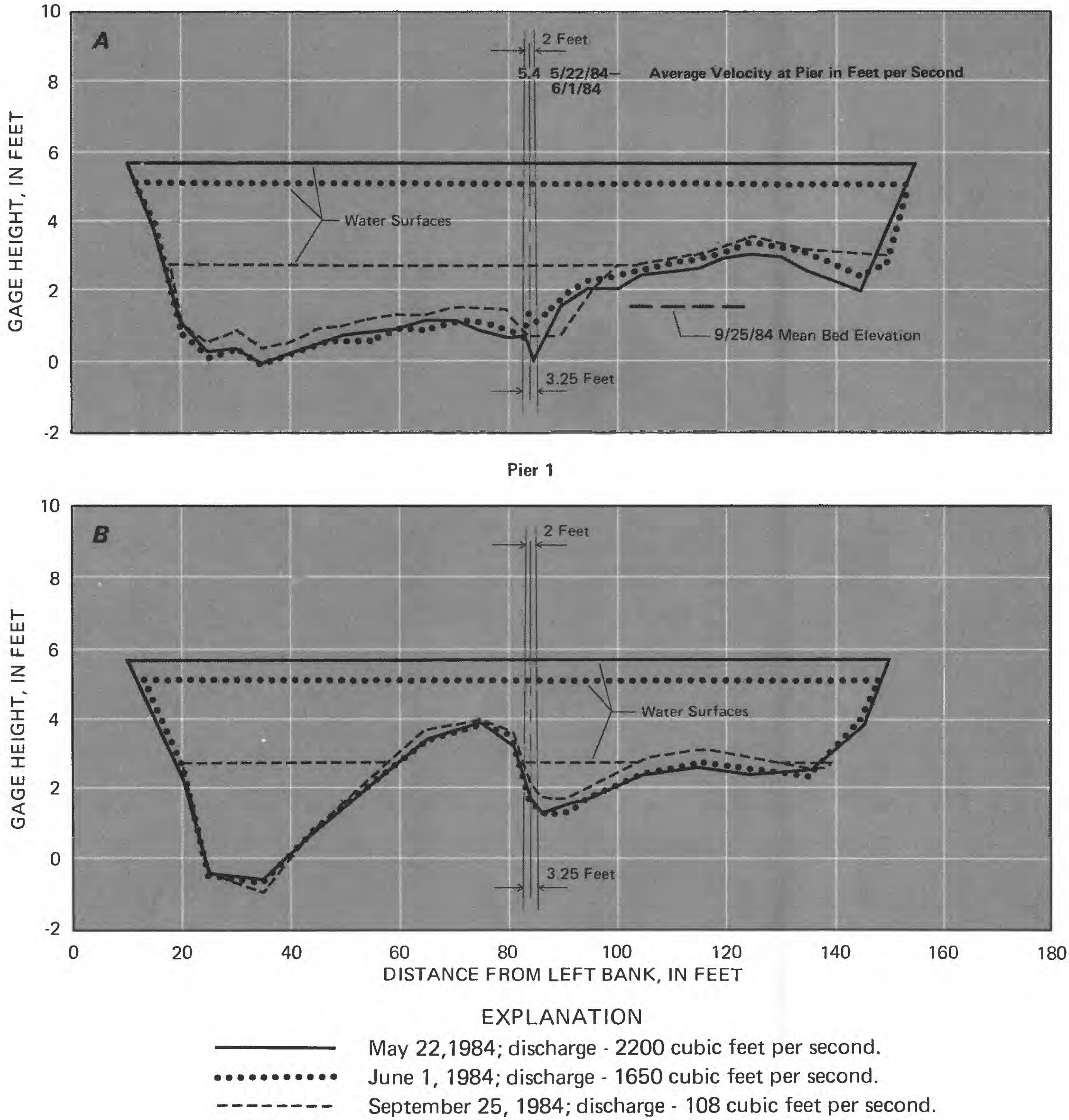
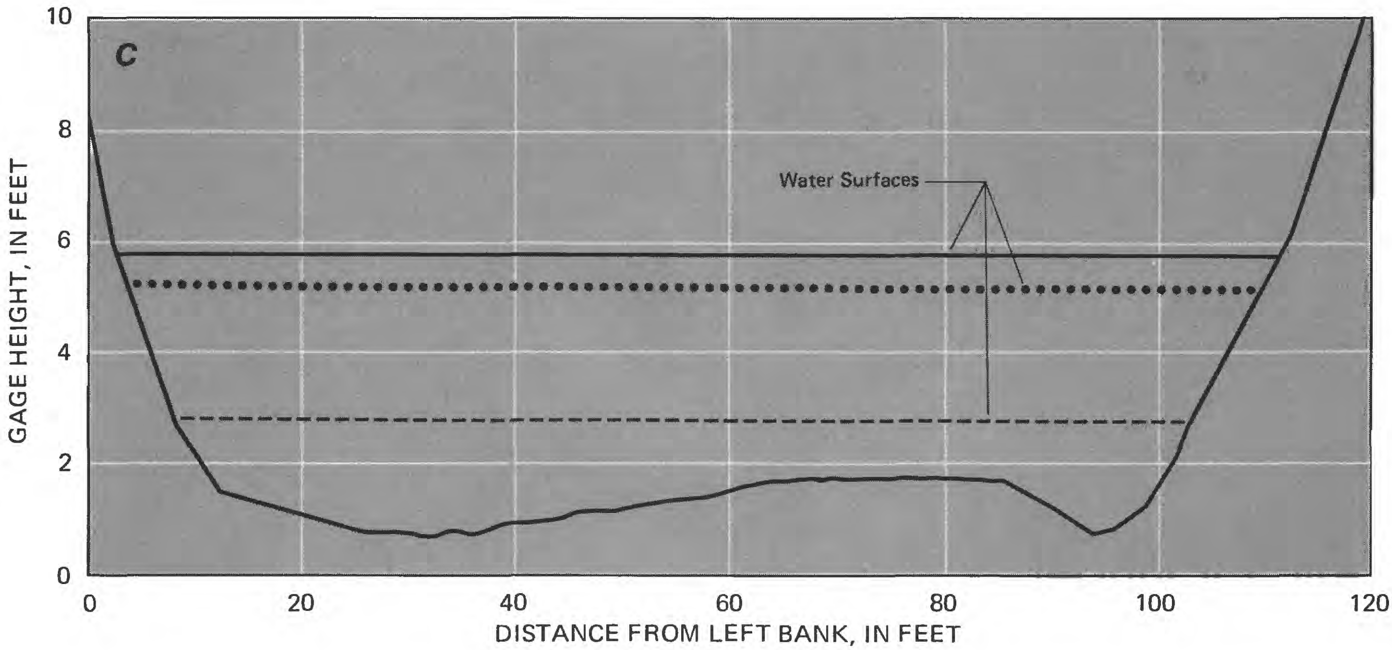


Figure 9.--Cross sections of bridge, Rio Grande at Monte Vista: (A) Upstream; (B) Downstream.



EXPLANATION

May 22,1984; discharge - 2200 cubic feet per second.
June 1, 1984; discharge - 1650 cubic feet per second.
September 25, 1984; discharge - 108 cubic feet per second.

Figure 9(C).--Approach cross section, Rio Grande at Monte Vista.

Table 2.--*Summary of collected hydraulic data*

[mo, month; yr, year; dashes indicate data not available]

Date of measurement (mo-day-yr)	Discharge (cubic feet per second)	Average approach velocity (feet per second)	Average approach depth (feet)	Froude number	Average surface-water slope (feet per feet)
		South Platte River near Kersey			
05-21-84	6,630	5.52	4.83	0.44	--
06-26-84	2,250	3.83	2.43	.43	0.00093
10-03-84	1,240	2.64	1.95	.33	.00094
		South Platte River at Masters			
05-18-84	8,010	4.57	5.85	0.36	--
06-25-84	2,750	3.24	3.10	.35	.00138
10-02-84	1,450	2.40	1.87	.31	.00126
		Arkansas River near Nepesta			
05-23-84	2,460	3.29	5.20	0.35	.00015
06-05-84	3,690	4.77	5.30	.50	.00075
09-27-84	363	1.74	.80	.34	.00050
		Rio Grande at Monte Vista			
05-22-84	2,200	5.05	4.01	0.44	.00149
06-01-84	1,650	4.42	3.52	.42	--
09-25-84	108	.81	1.41	.12	.00022

Table 3.--*Summary of bed-material sizes*

[mo, month; yr, year]

Location	Date of measurement (mo-day-yr)	Statistical size distribution, in feet, for the following percentiles						
		16	25	50	75	84	90	95
		South Platte River near Kersey						
Main channel	06-26-84	0.0014	0.0019	0.0036	0.0106	0.0168	0.0243	0.0342
Main channel	10-03-84	.0014	.0021	.0059	.0169	.0258	.0348	.0485
		South Platte River at Masters						
Main channel	06-25-84	0.0017	.0027	.0075	.0196	.0308	.0419	.0552
Pier	06-25-84	.0013	.0016	.0031	.0077	.0115	.0157	.0229
Main channel	10-02-84	.0019	.0027	.0050	.0134	.0206	.0273	.0363
Pier	10-02-84	.0010	.0013	.0022	.0051	.0069	.0181	.0305
		Arkansas River near Nepesta						
Main channel	06-05-84	.0010	.0012	.0018	.0029	.0035	.0055	.0099
Pier	06-05-84	.0013	.0018	.0039	.0111	.0169	.0241	.0351
Main channel	09-26-84	.0011	.0013	.0021	.0030	.0039	.0057	.0094
Sandbar	09-26-84	.0008	.0010	.0015	.0026	.0031	.0040	.0058
Right channel	09-26-84	.0011	.0014	.0022	.0030	.0034	.0048	.0060
		Rio Grande at Monte Vista						
Main channel	06-01-84	.0022	.0040	.0141	.0639	.0831	.0913	.0982
Main channel	09-25-84	.0014	.0022	.0264	.0461	.0640	.0835	.1014
Pier	09-25-84	.0289	.0464	.0978	.1900	.2260	.2474	.2651

velocity measured in front of the piers for the two larger discharge measurements also is shown in figures 6A, 7A, 8A, and 9A. Interestingly, these velocities generally were 10 to 30 percent slower than measured velocities between the piers at the South Platte River sites near Kersey and at Masters.

ESTIMATED SCOUR DEPTHS

The interpretation of the bed profiles to determine scour depths is not an easy task. The objective of measuring scour depths is to measure the same type of scour as measured in laboratory studies so results can be compared and extrapolated. It is a problem to identify whether the scour measured is caused by local or general scour. Estimation of scour depth is complicated by streambed conditions, debris, effects of multiple piers, distribution of flow, and definition of a reference elevation to measure scour. Inspection of the upstream side of bridge cross sections in figures 6A, 7A, 8A, and 9A shows the uneven and changed streambed surfaces and the problems of estimating the type and depth (measured to what reference elevation) of scour.

Two methods for calculating scour depths are presented. The first method is based on methods to calculate the total scour used in previous onsite studies (Norman, 1975). In this method, the total scour is determined at the upstream side of the bridge cross section as the difference between the minimum bed elevation for the date of measurement and the low-flow mean bed elevation. The low-flow mean bed elevation of each upstream side of the bridge cross sections is shown in figures 6A, 7A, 8A, and 9A. The total scour depths are shown in table 4. The second method presented is used to estimate the local scour at a pier. The estimated local scour is determined at the upstream side of the bridge cross section as the difference in the bed elevation at a pier for the date of measurement and the highest bed-elevation measurement at the same pier as shown in figure 8A. Only one local scour depth for each measurement, corresponding to the pier that had the greatest local scour, is shown in table 4. The local scour estimates at the pier probably include some general scour.

COMPARISON OF MEASURED AND PREDICTED BRIDGE PIER SCOUR

Thirteen local-scour-prediction equations were evaluated using the data collected during this study; they are cited in National Cooperative Highway Research Program (1970), Anderson (1974), Hopkins and others (1980), and were selected because they are used extensively and demonstrate the range of estimated local scour. More complex equations were not used because characteristics were not easily measured or used. The important data used in the 13 equations are average approach velocity, average approach depth, pier width, Froude number, and average bed-material size (Shen and others, 1969; Richardson and others, 1975). Following is a short summary of the selected equations. (See Hopkins and others (1980) for complete reference. The dates are shown to indicate relative time the equations were developed.)

Table 4.--*Comparison of measured and predicted scour depths using selected equations*

[mo, month; yr, year; numbers in parentheses are equation numbers in text]

Date of measurement (mo-day-year)	Measured scour depth (feet)	Local scour depths (feet) determined using local-scour-prediction equations developed by the indicated investigators												
		Laursen (1)	Shen (2)	Shen (3)	Breuser (4)	Blench (5)	Blench (6)	Blench (7)	Inglis-Poona(8)	Inglis-Poona(9)	Chitale (10)	Bata (11)	Varzeliotis (12)	Carstens (13)
						South Platte River near Kersey								
05-21-84	[1]7.4 [2]3.2	3.4	10.4	4.9	2.5	2.0	2.0	3.9	5.8	1.9	6.6	9.4	3.3	1.0
06-26-84	[1]6.0 [2]1.7	2.7	5.0	3.7	2.4	1.6	1.6	1.9	3.7	1.5	3.3	4.4	2.4	1.0
						South Platte River at Masters								
05-18-84	[1]5.4 [2]5.0	2.5	7.1	2.8	1.3	0.8	0.8	4.7	3.4	0.9	6.4	6.3	1.0	0.5
06-25-84	[1]6.0 [2]5.0	2.0	3.6	2.3	1.3	1.0	1.1	2.5	2.5	1.0	3.3	3.0	1.2	.6
						Arkansas River near Nepesta								
05-23-84	[1]6.0 [2]2.2	5.8	3.7	5.9	5.6	3.6	3.6	4.1	4.9	3.3	4.3	3.3	3.0	2.2
06-05-84	[1]8.6 [2]4.8	5.9	7.8	7.6	5.6	3.6	3.6	4.2	7.1	3.3	6.3	7.0	4.6	2.2
						Rio Grande at Monte Vista								
05-22-84	[1]1.7 [2]1.2	4.1	8.7	5.8	3.5	2.4	2.4	3.2	5.9	2.2	5.5	7.5	3.8	1.5
06-01-84	[1]1.8 [2] .5	4.1	6.7	5.4	3.6	2.3	2.4	2.8	5.2	2.2	4.6	5.6	3.5	1.7

[1]Total scour determined by the difference between the minimum bed elevation for the date of measurement and the low-flow mean bed elevation.
[2]Local scour determined by the difference in the bed elevation at a pier for the date of measurement and the highest bed-elevation measurement at the same pier.

1. Laursen equation--1956 and 1958:

$$D = 1.5b^{0.7}H^{0.3}, \tag{1}$$

where D = scour depth measured from mean bed elevation, in feet;
b = width of the pier, in feet; and
H = flow depth (stage).

The Laursen equation was transcribed by Neill (1970) based on Laursen's basic design curve for a square-nosed pier aligned with the flow as reported in Laursen and Toch (1953) and in additional reports by Laursen (1958, 1962).

2. Shen and others equations--1969:

(a)
$$\frac{D_e}{b} = 11.0F_p^{2} \tag{2}$$

(b)
$$\frac{D_e}{b} = 3.4F_p^{0.67}, \tag{3}$$

where D_e = scour depth at equilibrium measured from mean bed elevation, in feet;
F_p = pier Froude number = $V/(gb^*)^{0.5}$: where V = flow velocity, in feet per second; g = acceleration of gravity, in feet per second squared; and
b^* = width of the pier projected on a plane normal to undisturbed flow, in feet.

3. Breusers equation--1964:

$$D_{max\ e} = 1.4b^*, \tag{4}$$

where $D_{max\ e}$ = maximum scour depth at equilibrium measured from mean bed elevation, in feet.

4. Blench equations--1960:

(a)
$$\frac{D^*}{d_r} = 1.8(b/d_r)^{0.25} \tag{5}$$

(b)
$$\frac{D^*}{H} = 1.8(b/H)^{0.25} \tag{6}$$

(c)
$$D^* = 1.8(d_r), \tag{7}$$

where D^* = scour depth measured from the water surface, in feet; and

d_r = regime depth = $(q^2/F_b)^{0.33}$, in feet; where q = VH, in feet squared per second; and F_b = bed factor = V^2/H, in feet per second squared.

5. Inglis-Poona equations--1949:

(a)
$$\frac{D^*_{max}}{b} = 1.7(q^{0.67}b)^{0.78} \quad (8)$$

(b)
$$\frac{D^*_{max}}{b} = 1.73(H/b)^{0.78}, \quad (9)$$

where D^*_{max} = maximum scour depth measured from the water surface, in feet.

6. Chitale equation--1962:

$$\frac{D}{H} = 6.65F-5.49F^2-0.51, \quad (10)$$

where F = Froude number = $V/(gH)^{0.5}$.

7. Bata equation--1960:

$$\frac{D}{H} = 10 \left(\frac{V^2}{gH} - \frac{3d}{H}\right), \quad (11)$$

where d = diameter of bed material, in feet.

8. Varzeliotis equation--1960:

$$\frac{D^*_{max}}{b} = 1.43(q^{0.67}/b)^{0.72} \ . \quad (12)$$

9. Carstens equation--1966:

$$\frac{D_e}{b} = 0.546[(N_s{}^2-1.64)/(N_s{}^2-5.02)]^{0.83}, \quad (13)$$

where N_s = the sediment number = $V/[(s-1)gd_m]^{0.5}$; where s = specific gravity of the sand = 2.65; and d_m = mean diameter of bed material, in feet.

A summary of the comparison of the measured and predicted scour depths for the selected scour-prediction equations is listed in table 4. When evaluating the equations, several points need to be remembered. The 13 equations were developed to estimate local scour, whereas method 1 (see footnote in table 4) calculates the total scour, and method 2 (see footnote in table 4) attempts to calculate the local scour. The scour depths measured, particularly local scour, may indicate scour depths resulting from another discharge prior to the measurement, but the scour hole had not reached equilibrium. Differences in measured and predicted scour depths could be due to the method of defining a reference elevation to calculate scour depths. Similarly, only a low-flow approach cross section was available to define the approach velocity and mean depth which were used in the scour-prediction equations. The Rio Grande is a gravel-bed river, and the equations may not be applicable for this size bed material; hence, the predicted local scour values only were tested for comparative purposes and interpretive results were not made.

The scour depth was measured in a plane immediately upstream or downstream from the face of the bridge (although the flow may have deflected the sounding weight downstream somewhat) and is a limitation to collecting scour data using the techniques presented in this report. Ideally, the measurements should be made to reflect the maximum scour. As noted in the discussion for each site, debris buildup around some piers was a problem, and the effect of this debris on scour varies. In some instances, debris protected the channel at the base of the pier and reduced the scour; and in other instances, debris increased the effective pier width and increased the scour. The measurement during the site visits of maximum scour depth at a pier through time indicated that there were no measurable differences resulting from bed-material movement. For flows larger than the measured flows, there probably would be changes caused by the passage of dunes; hence, this measurement needs to be done. As described by Jones (1984), the prediction equations resulted in a range of local scour estimates. For example, for the South Platte River near Kersey site for May 21, 1984, the prediction equations estimated local scour ranging from 1 to 10.4 feet as compared to the measured local scour of 3.2 feet. Interestingly, the predicted local scour values were less than the total measured scour values (method 1, see footnote in table 4) for 73 of 78 estimates. Comparing the predicted local scour with the measured local scour (method 2, see footnote in table 4) indicated that 50 of 78 predicted local scour values exceeded the measured local scour values. The prediction equations could not accurately estimate local scour for the South Platte River at Masters, possibly because of the large number of piers or contraction scour. Because local scour measured by method 2 includes some general scour, the equations were not very accurate for this method. For all the sites, except South Platte River near Kersey, some of the scour differences in table 4 are explained in the following paragraphs.

The measured local scour depth of 5 feet on June 25, 1984, at South Platte River at Masters is larger than expected for its discharge of 2,750 cubic feet per second. It was expected to have been less than the local scour depth of 5 feet measured on May 18, 1984, at this site. The discharge on May 18, 1984, was 8,010 cubic feet per second. The excessive scour probably was caused by lateral shifting of the river bed. The shift of the main channel to the right increased the flow along the right side, which also increased the velocity on the right side (fig. 7A). This increase in velocity probably is the cause of increased scour. The center of the river bed is lower for the October 2, 1984, measurement (1,450 cubic feet per second) than for the June 25, 1984, measurement (2,750 cubic feet per second) as shown in figure 7A. The maximum scour for the October 2, 1984, measurement is located 159 feet from the left bank (fig. 7A). This is along the right edge of a sandbar that is contracting the flow. The scour at this location probably is due to a combination of local scour at pier 4 and erosion of the sandbar, which are results of the greater local velocity associated with the contraction.

At Arkansas River near Nepesta, the predicted local scour depths for most of the equations were larger than the measured scour depth for the May 23, 1984, measurement. Because the approach cross section could not be measured during high flows at this site, the low-flow approach cross section was used to estimate the average approach velocity and depth for the high-flow measurements. The channel bed probably was unstable at the approach cross section. An indication of this is that the channel bed on the upstream side of the bridge was unstable (fig. 8A), which is only about 100 feet downstream from the approach cross section. Also, there were dunes along the left side of the approach cross section. Therefore, if the estimates of the average approach velocity and depth were significantly different from their actual values, the difference would affect the predicted scour depths.

At Rio Grande at Monte Vista, the predicted scour depths for all of the equations for the May 22, 1984, and the June 1, 1984, measurements are larger than the measured values; all the scour-prediction equations used were determined using data for sand-bed channels, whereas, Rio Grande at Monte Vista is a gravel-bed channel, and the pier is not a simple-shaped pier. The scour depth at the pier was greater for the September 25, 1984, measurement (108 cubic feet per second) than for the June 1, 1984, measurement (1,650 cubic feet per second) as shown in figure 9A. Most of the flow is to the left of the pier, but deepest local scour is to the right of the pier. This deep local scour probably was caused by contraction of a larger flow after the June 1, 1984, measurement by a gravelbar along the right bank. Also, a gravelbar along the left side of the pier (fig. 9B) and underneath the bridge caused more water to flow around the right side of the pier as shown in figure 4. The greater velocities associated with this flow probably increased the scour on the right side of the pier.

EVALUATION OF THE PILOT STUDY

This section of the report is a summary of the pilot study of the bridge-pier scour-data-collection program. Flow conditions, equipment used to measure velocity and scour depth, and the measurement conditions are evaluated.

Flow Conditions

More complete data could have been collected during the spring runoff if the pilot study had been started earlier. However, the project was not conceived until early spring when runoff was anticipated to be high. Although there was significant flooding in Colorado during the spring of 1984, the channels selected for study had relatively small floods because of unpredictable, early, and gradual melting of the snowpack in the river basins. The high-flow forecasts were imprecise and, at most sites, the peak flows had already occurred. More accurate streamflow estimates would benefit the timing of data collection. More than three data collections need to be made at each site to define a mean bed elevation as a basis for computing scour, to evaluate the scour equations, and to develop refined or new scour equations.

Equipment Used to Measure Stream Velocity and Scour Depth

Stream velocity and depth are difficult to measure if there are fast velocity flows and debris present. Both are common problems during floods and result in missed data particularly near piers where local scour depths generally are deepest. Measurement of velocity and depth from the upstream and downstream sides of a bridge does not result in a three-dimensional view of the channel bottom. The maximum scour may not be measured, particularly if the maximum scour occurs under the bridge. However, for a simple-shaped pier and parallel flow, the maximum scour generally occurs in front of the pier (Norman 1975). There are other methods of collecting data, including the use of fathometers and the use of boats, that were not evaluated because of associated hazards, time constraints, and availability of equipment.

A Bludworth fathometer was used in this study to test ultrasonic devices that measured the depth of flow and scour holes. A fathometer has problems measuring depths when used during faster velocities. It is difficult to hold a fathometer vertically in the water without making incorrect depth measurements because of air bubbles. Fathometers also generally are not locally available; therefore, many onsite personnel do not know how to use them. However, fathometers do have an advantage because they can be mounted either on boats or floating devices if stream velocities are not too fast (Hopkins and others, 1980). The streambed then could be mapped to indicate a three-dimensional view of the streambed. To better determine the velocity and approach depth for high flows, which are significant parameters in predictive equations, construction of cableways upstream from sampling sites may be beneficial.

Measurement Conditions

Working conditions for this pilot study were nearly ideal. The weather generally was warm, and there was little precipitation and usually no strong winds. The streamflows were relatively steady for several days because of gradual melting of the snowpack, and there was not much debris in the flow. For these conditions and for the types of data collected, it generally took a two-person crew 7 to 10 hours to collect the data at one bridge site. Adverse weather would increase the time needed for collecting the data. During floods, stage generally changes faster with time, particularly during flash floods, and the flows could contain more floating debris. During these floods, data collection would be more difficult, and there would be much less time available for collecting detailed data; hence, more people per crew would be preferable. More data collected at a site would help determine the quantity and types of scour and help improve the estimate of a reference elevation to measure scour depths.

ALTERNATIVES FOR FURTHER DATA COLLECTION

A bridge-pier scour study needs preliminary planning to maximize the benefits of the study. In this stage of the study, the site selection and the type of study need to be evaluated. Equipment and methods for different types of studies are presented. Needs for post-failure investigations that would complement bridge-pier scour data are reviewed.

Preliminary Planning

The following project planning needs to be done before data collection:

1. Identify areas where high flows are expected to occur.

2. Determine the type of flooding to know how much advance time is needed, the duration of high flows, and the seasons in which the flooding occurs. (This information can be obtained from the U.S. National Weather Service, the U.S. Soil Conservation Service, and the U.S. Geological Survey.)

3. Determine the type of measurement approach and data requirements.

4. Select bridge sites to set permanent markers and mark bridge railing for distance.

5. Obtain highway inspection records (when available, from the State or County highway departments).

6. Obtain a forecast of when probable high flows will occur at each site to collect scour data before, during, and after high flows. (These streamflow forecasts can be obtained from the U.S. National Weather Service and the U.S. Soil Conservation Service.)

7. Monitor the discharge or gage height at streamflow-gaging stations daily in the upper basin or at the site for each bridge site. For some rivers, this monitoring possibly can be done using satellite or telemeter stations at or near the selected bridge sites.

8. Determine historic sediment-discharge and bed-material data availability at bridge sites.

Site Selection

Site selection is an important factor in data collection. Appropriate sites are limited and difficult to identify. Initially, the sites need to be as simple as possible, that is, straight reaches of channel that have simple bridge geometry and where depth information at the piers can be measured from the bridge. As onsite data-collection methods become more refined, more complex channel and bridge configurations may be investigated. These sites would include bridges that are affected by piers, embankment constrictions, and possibly by long-term degradation and aggradation of the channel (if there are available studies to show long-term bed changes).

Bridge sites that are prone to scour need to be identified, and areas where high flows are anticipated during the study period need to be located. State Highway, U.S. Geological Survey, U.S. Federal Highway Administration, and local personnel (City and County) can be contacted for background information and advice regarding identification of sites where scour is likely to occur. Because of the randomness of flooding, more potential sites than actually will be monitored need to be selected. Scour data are needed for a variety of flow conditions and not just for the larger floods. Data from smaller floods generally will be easier to measure, and more data can be collected. Studying scour for a variety of conditions will provide more data per site (rather than limited data at many sites) to evaluate the scour processes. Sites where much of the desired data have been collected as part of the normal streamflow-gaging programs are most useful. Minimal pre-flood data could be obtained at all the potential sites, then final site selection could be made based on where floods actually occur. Following is an ideal procedure for selecting sites based on results of this study and the studies of others (Shen, 1971; Norman, 1975):

1. Identify the flood potential of the area.

2. Use a streamflow-gaging station that has a strip-chart recorder, located at or near a bridge site, for a quick reference to stage changes.

3. Ensure that a cableway exists upstream from the bridge site, or that there is a boat ramp if boats can be used.

4. Determine if scour-prone conditions exist at the bridge site, such as a sand-bed channel.

5. Determine if an ample supply of sediment is covering the bedrock and that there is no armoring effect or riprap on the streambanks. Be sure piers are not protected with riprap.

6. Ensure that bridge piers are simple shaped and located near the upstream face of the bridge. Ensure that piers do not constrict the flow area by more than 10 percent for local scour sites.

7. Ensure that flow is parallel to the piers.

8. Ensure that a minimal quantity of debris exists.

9. Ensure that there is uniform channel upstream and downstream from the bridge.

10. Ensure that there is easy accessibility to the site during high flows.

11. Ensure that there is minimal traffic crossing the bridge.

12. Ensure that there is minimal contraction of the channel at the bridge site.

13. Preferably, have a satellite or telemeter station at the site or nearby for daily monitoring of discharge.

Type of Approach

Depending on the objectives of a scour study and the flow conditions in the study area, either a limited or a detailed approach can be used to collect scour data. A scour study probably would be comprised of a combination of sites using each approach. The two approaches are described in the two following sections.

Limited Approach

If the study objectives are to estimate only the depth of scour that occurs at selected sites, to evaluate the accuracy of existing scour-prediction equations, and to determine where stage changes fairly rapidly, a limited approach to collecting data can be used. The types of data needed for a limited approach based on this study and the studies of others (Culbertson and others, 1967; Shen, 1971) are:

1. A standard discharge measurement and the gage height.

2. Cross section on the upstream side of the bridge, including scour depths in front of and close to the sides of piers.

3. Cross section on the downstream side of the bridge, including scour depths in front of and close to the sides of piers (optional).

4. Approach cross section and velocity upstream from the bridge (generally one bridge width) estimated from low-flow surveyed cross sections.

5. Average flow velocity from standard current-meter measurement on the upstream side of the bridge.

6. Bridge and pier geometry.

7. Visual observations of the water surface to determine bed form. See Simons and Senturk (1977) for discussion.

8. Photographs of channel and bridge at each visit to a site.

9. Bed-material samples.

10. Obtain bridge soil-boring data if available, from preconstruction drilling.

Some floods that occur are of short duration and provide minimal time for data collection. For these conditions, a flexible approach needs to be taken to obtain essential data in a minimum time. The data collected needs to include gage height and water-surface elevations (probably flagged and measured at a later time), depth sounding only on the upstream side of the bridge and piers (where the greatest scour is expected), and photographic documentation. Making depth soundings (without attached velocity meter) only on the upstream side of the bridge would decrease the drag and debris on the cable and would increase the chance of measuring the maximum scour. After the flood, additional data listed could be collected. Discharge at the time of measurement would be determined from stage-discharge rating-curve extensions (based on recession-flow discharge measurements) or would be determined by indirect methods (Benson and Dalrymple, 1967).

Detailed Approach

If the study objectives are to estimate the depth of scour, to evaluate selected scour-prediction equations, to obtain an improved understanding of the factors affecting scour, to develop new scour-prediction equations, and to determine where stage changes vary gradually with time, then a detailed approach to collecting data needs to be used. A detailed approach would enhance the separation and definition of the total scour into its three components--local, general, and degradation and aggradation. In addition to the data needed for a limited approach, the types of data needed for a detailed approach based on this study and the studies of others (Culbertson and others, 1967; Shen, 1971; Norman, 1975) are:

1. Water-surface profiles upstream and downstream from the bridge.

2. Water-surface elevations on the upstream and downstream sides of the bridge.

3. Approach cross section and velocity upstream from the bridge (generally one bridge width) during the measurements. A cableway or boat-measuring site could be constructed for the scour project.

4. Bed-material samples from the channel and in the scour holes.

5. Suspended-sediment load.

6. Vertical-velocity profiles to define the flow patterns.

7. Longitudinal streambed profiles to use with item 1 to map the geometry and bed form of the streambed.

8. Water temperature.

9. Measurement of bed elevation at a point throughout a period of time.

Equipment and Methods for Limited or Detailed Approach

Equipment used for either a limited or a detailed approach are approximately the same as for the pilot study described in the "Data Collection Equipment" section. Only equipment and methods not described in that section will be described here.

No sites were available for the pilot study where cableways were located upstream from the bridge, which was a major limitation. If sites are available that have cableways near the approach cross section (or if a cableway could be built as part of a detailed study), depth soundings and velocities could be obtained (item 3, "Detailed Approach" section) for all flow conditions. If high flows are not too hazardous, a boat equipped with a depth-sounding and velocity meter or a fathometer could be used.

In addition to the bed-material samples, suspended-sediment samples are useful when determining the water-sediment mixture and its effect on depth of scour. Sediment concentration of the flow is measured by collecting depth-integrated, suspended-sediment samples at equally spaced verticals across the stream and using an equal-transit-rate (ETR) method at all intervals (Guy and Norman, 1970). When the stream is shallow and can be waded or when a low bridge is accessible, the US DH-48 wading-type hand sampler is used (Guy and Norman, 1970). For flow depths as much as 16 feet, the US D-74 62-pound sampler generally is used. For flow depths as much as 180 feet, the US P-61 105-pound sampler generally is used. For more detailed information about suspended-sediment sampling equipment or methods, refer to Guy and Norman (1970) and U.S. Geological Survey (1977).

In addition to obtaining velocity measurements across the stream to determine lateral distribution and variation, collecting velocity profiles with depth also would provide valuable information. Velocity-profile measurements as described by Rantz and others (1982) could be made between piers and as close as possible to the piers. For example, Marchand and others (1984) collected velocity profiles at 11 sites in Colorado, including the South Platte River at Kersey which shows the velocity distribution with depth of flow. To determine the direction of flow beneath the water surface (because it may differ from that at the surface), a velocity-azimuth-depth assembly (VADA) or similar equipment could be used (Rantz and others, 1982). The VADA combines a sonic sounder with a remote-indicating compass and Price AA current meter to record depth, indicate direction of flow, and enable measurement of velocity at any point. Water temperature is obtained by immersing a standard thermometer in the water at bankside.

Several types of existing or new scour-measuring equipment or new techniques may provide alternative methods to measuring scour. Leopold and others (1964) and Jain and Fischer (1980) have demonstrated the use of buried vertical chains to determine the maximum depth of scour (at the depth that the chain is no longer vertical). Chains would have the greatest use in streams that have periods of no flow where access would be possible.

Hopkins and others (1980) describe a mobile truck-mounted, crane-operated fathometer-transducer float system for measuring bed elevations upstream and downstream from bridges. This system has some capabilities for mapping the streambed in the vicinity of the bridge. Hopkins and others (1980) also describe three float-mounted fathometer transducers to measure bed elevations. These systems also have the potential to map the streambed in the vicinity of the bridge. This equipment may not work in extremely turbulent water or where debris is present.

Dean (1981) describes an impulse-radar system that has very accurate profiling capabilities and varied application as a low-level remote-sensing tool. Continuous depth sounding in the vicinity of bridges can be made through debris, ice, and in air-entrained waters. The system is very mobile and has the capability of identifying dune passage and depth of scour. The limitation of the impulse-radar system is that radar waves traveling through water attenuate rapidly; however, their range may be sufficient for many bridge-scour studies. Dean (1981) and Ulriksen (1982) indicate that the radar works very well in low-conductivity fresh water.

Laenen (1983) describes an acoustic velocity meter to measure the velocity and depths across a stream. The system was used on the Cowlitz River at Castle Rock, Wash., to measure streambed-elevation changes. Laenen also demonstrated that the system could measure the height of dunes moving through the cross section containing the measuring system.

Skinner (in press) describes the design of an instrumented, unmanned boat that can be launched and controlled from a bridge and can be maneuvered in flood flows that reach velocities of 15 feet per second. Although the boat is untested for onsite conditions (as of 1986), it has great potential for mapping the streambed in the vicinity of piers using radar or ultrasonic devices as described above.

Methods for Post-Failure Investigations

Supplying bridge engineers with documentation of potential causes for bridge failures would complement the scour data collected. At present, there exists little documentation concerning the causes of bridge failure. Bridge-scour data and documentation on damage from failure of bridges should provide information to prevent future bridge failures. Personnel who measure floods commonly make discharge measurements from bridges during the passage of a flood or they make indirect measurements of peak discharge immediately following a flood; therefore, they can make observations about the effects of the flood on the bridge. The following information would help bridge and hydraulic engineers in their assessment of damage or failure of bridges:

1. Location of bridge. Many bridges have highway mileage posts.

2. Date and general description of the precipitation and flooding.

3. Estimation of the quantity of velocity-head buildup and direction of flow at the piers.

4. Quantity and type of debris around the bridge.

5. Estimation of the depth and width of water over the road.

6. Description of erosion caused by overtopping of the embankment.

7. Description of cracks in the bridge.

8. Description of abrasion of abutments or piers.

9. Evidence and depth of settling of the bridge.

10. Photographic documentation of 1-9.

11. Notification of the appropriate highway office and report observations.

12. Discussions of flooding conditions with any possible observers.

SUMMARY

Scour around bridges is a serious problem on many rivers; bridge failure commonly is attributed to undermining of piers or abutments by scour. A pilot study was made at four bridge sites in Colorado to develop and test limited and detailed guidelines for collecting scour data onsite during and after high flows. These guidelines are viable and relatively low cost. They could potentially be used to make a bridge-scour study or to establish a nationwide bridge-scour data collection program in conjunction with normal high-flow measurements. The methods tested are compatible with equipment and procedures commonly used in the U.S. Geological Survey streamflow-gaging program. A primary advantage of this approach is that it benefits from the experience of a large number of personnel who routinely work with flood-measuring equipment in addition to their mobility and the availability of equipment.

The sampling program for this study consisted of collecting scour data at four bridge sites during the leading edge, peak, and recession periods of flow. The data collected primarily consisted of discharge and gage height measured upstream and downstream from the bridge-channel cross sections, scour depths and velocity near piers, approach-channel cross section and velocity, water-surface profiles, bed-material samples, bridge geometry, and photographs. Measurements for this study were for fairly steady flow. For these steady-flow conditions, it generally took a two-person crew about 7 to 10 hours to collect the data at one bridge site. Because many floods occur during less ideal weather conditions and because flow often is unsteady, the collection of the same data would likely take longer. However, because of the unsteady flow, less time would be available to collect these data.

The accuracy of 13 local scour-prediction equations was evaluated using scour data collected during this study. Two methods were used to estimate the total scour and the local scour at bridges. The local scour-prediction equation values were less than the total measured scour values in 73 of 78 estimates. However, the predicted local scour values exceeded the measured local scour values in 50 of 78 estimates. Some of this overestimation may be because of the difficulty of measuring the depth of scour near the pier. Because of limited bridge-scour data, definition of a reference plane from which to measure scour and determination of local and scour depths from the total measured scour are difficult.

Two alternative approaches for future, proposed scour studies are indicated. The type of approach would depend on the objectives of the scour study and the flow conditions in the study area. A limited-approach study would be done if the study objectives are to estimate the depth of scour that occurs at a site, to evaluate scour-prediction equations, and to determine those sites where stage changes fairly rapidly. A detailed-approach study could be done if the study objectives are to estimate the depth of scour, to evaluate scour-prediction equations, to improve the understanding of scour processes, to refine or develop new scour-prediction equations, and to determine if the high flows are fairly steady. A regional study could be comprised of a combination of sites from each approach. A major emphasis in future onsite studies needs to be the collection of more data at a given site and for a variety of flow conditions. To augment bridge-scour data, documentation of the potential causes of bridge damage and failure also is needed.

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