# SCOUR AT SELECTED BRIDGE SITES IN MISSISSIPPI

By K. Van Wilson, Jr.

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## CONVERSION FACTORS AND VERTICAL DATUM

| Multiply | By | To obtain |
|---|---|---|
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second |
| foot (ft) | 0.3048 | meter |
| foot per mile (ft/mi) | 0.1894 | meter per kilometer |
| foot per second (ft/s) | 0.3048 | meter per second |
| pound per square foot ($lb/ft^2$) | 47.88 | newton per square meter |
| square mile ($mi^2$) | 2.590 | square kilometer |

**Sea level**: In this report, "sea level" refers to National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

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## ABSTRACT

Scour data were collected during 1938-94 at 22 selected bridge sites in Mississippi. The drainage area of the bridge-scour sites ranged from 60.8 to 5,720 square miles, and the slope in the vicinity of each site ranged from 0.00011 to 0.00163 foot per foot. Measured pier-scour depths ranged from 0.6 to 20.4 feet. Measured total-scour depths at minimum-bed elevation ranged from 5.2 to 29.8 feet. Recurrence intervals of measured discharges ranged from less than 2 to about 500 years. At several sites, measured scour depths were possibly affected by heterogeneous bed material, primarily where a clay stratum was overlain by sand or gravel. Limited data indicate the pier-scour depths decreased as shear strength of the clay increased. Debris piles significantly obstructed more of the approach flow than the pier for some measurements. The normal width of the largest debris pile was as much as 1.5 times the actual pier width.

All of the Mississippi pier-scour depths were within 2.3 times the normal pier width, which agreed with previous research. Only 12 (6 percent) of the 190 measured pier-scour depths were greater than 1.1 times the normal pier width. Measured pier-scour depths were as much as 2.24 times a normal pier width of 3.3 feet. However, for pier widths greater than about 4 feet, measured pier-scour depths were significantly less than 2.3 times the normal pier width.

An envelope-curve equation for the Mississippi pier-scour data was developed by relating pier-scour depth divided by normal pier width to approach-flow depth divided by normal pier width. Measured pier-scour depths were compared to computed pier-scour depths using this envelope-curve equation and using the scour-prediction equation currently (1994) recommended in the Federal Highway Administration Hydraulic Engineering Circular No. 18 (HEC-18). The HEC-18 equation predicted pier-scour depths ranging from 3.9 to 25.7 feet with residuals (measured pier scour minus computed pier scour) ranging from -21.7 to 0.2 feet. The envelope-curve equation developed during this study, excluding one distorted measurement, predicted pier-scour depths ranging from 2.2 to 19.7 feet with residuals ranging from -16.8 to 0.5 feet. The envelope-curve equation predictions could be used for reasonable verifications of the HEC-18 pier-scour predictions, which currently are required for the design and maintenance of bridges in Mississippi.

## INTRODUCTION

Exposure or undermining of bridge pier and bridge abutment foundations by the erosive action of flowing water, including tidal currents, can result in structural failure of a bridge. Bridge failure results in large capital expenditures for repair or replacement and may cause loss of life. Davis (1984) documented case histories of scour problems at bridges in the United States. Scour of the ground in the vicinity of bridge piers and abutments during floods has resulted in more bridge failures than all other causes in recent history (Murillo, 1987). Many bridges in

Mississippi are at risk of failure due to scour. The design and maintenance of bridge foundations require consideration of the maximum depth of scour that could occur during an extreme flood. Bridge pier and abutment foundations need to extend below the anticipated maximum scour depths to provide support for bridges if scour does occur.

The term "scour," as used here, is defined as the lowering of the ground by erosion below an assumed natural level or other appropriate datum. "Scour depth" is the depth to which material is removed below the stated datum. Scour is a natural phenomenon that is of primary concern in alluvial streams. However, scour can be a problem in any waterway having erodible bed materials. Scour around bridges can be the result of any one of, or combination of, three interrelated components.

- **Local scour** - erosion caused by local disturbances in the flow, such as vortices and eddies near piers, abutments, and debris piles.
- **Constriction scour** - erosion caused by increased flow velocities through a bridge opening due to the decreased flow area formed by the bridge, the approach embankments, the piers, and any debris piles.
- **General scour** - progressive degradation caused by natural processes or by changes in channel controls that occur over a long channel reach and, possibly, over many years. General scour could be part of a temporary fluctuation about some mean bed level. This is the scour that occurs in a channel even if no bridge is present.

Although these components of scour are not completely independent, general practice in bridge design is to estimate each component of scour separately and to combine the predicted scour depths to estimate the total scour depth at a bridge site.

Many empirical equations have been developed to compute constriction scour and local scour at bridges. These equations can provide a large range of scour depths for the same set of conditions. Most of the equations are based on scale-model laboratory experiments and have not been field verified due to the lack of onsite high-flow data. Bridge designers and bridge inspectors need more onsite high-flow data to validate computed scour depths for the varying conditions that occur in Mississippi and throughout the United States.

Adequate definition of potential scour at bridge sites is essential to proper bridge design, construction, and maintenance. Accurate estimates of scour depths for varying conditions are a prerequisite for safe, cost-effective bridge design. Underestimating scour depths puts bridges and human life at risk. Overestimating scour depths results in overdesign, which translates into an economic loss in the form of higher construction costs. Collection of onsite scour data is recognized as one way, and perhaps the only convincing way, to improve bridge design procedures (Highway Research Board, 1970; Hopkins and others, 1980; Jones, 1984; Laursen, 1984; Murillo, 1987).

The U.S. Geological Survey (USGS), in cooperation with the Mississippi Department of Transportation (MDOT), began a study of bridge scour in Mississippi in 1989. The objectives of this study were to: (1) perform onsite high-flow scour measurements at selected bridge sites, (2) evaluate the usefulness of available scour equations for estimating local pier scour, (3) develop a scour-prediction equation that could be used to better estimate local pier scour for Mississippi streams, and (4) analyze available discharge measurement soundings for an indication of total scour.

## Purpose and Scope

This report summarizes scour data collected during 1938-94 at 22 selected bridge sites in Mississippi (fig.1). The methods used to measure scour and selected characteristics at each site are described. Selected hydraulic and bridge-geometry characteristics are presented. An envelope-curve equation for the Mississippi pier-scour data was developed by relating measured pier-scour depth divided by normal pier width to measured approach-flow depth divided by normal pier width. The measured pier-scour depths were compared to the envelope curve and to the pier-scour prediction equation recommended in the Federal Highway Administration (FHWA) Hydraulic Engineering Circular No. 18 (HEC-18) by Richardson and others (1993). Total-scour depths were determined from minimum-bed elevations obtained from discharge measurements at each site.

## Methods of Study

The scour data collection sites for this report were selected from a list of sites known by the MDOT to be susceptible to scour. Data were also obtained at a few additional sites if, during the study, high flow occurred at a site and the USGS and the MDOT considered the data useful for bridge maintenance. Scour data were collected as near the peak discharge as possible. If the high flow was of sufficient duration, additional measurements were obtained during the rising and falling limb of the flood hydrograph.

Measurements of water depth and velocity to determine discharge were obtained using standard streamflow-gaging procedures as described by Rantz and others (1982). Depth, vertical position, and velocity were measured by suspending a 100-, 150-, or 200-pound Columbus-type sounding weight and Price AA-type current meter in the water.

Soundings to the channel bed to measure channel geometry were obtained either by sounding with a weight or with an Eagle Model Mach 1 Graph[1] recording fathometer. Transducers used with the fathometer produced an 8-degree beam width, allowing close access to bridge piers without creating echoes off the sides of the pier. Use of the fathometer made soundings possible at a large number of points across a cross section. During high flows, the transducer was attached to the bottom of the sounding weight, which was lowered into the water from a truck-mounted boom and winch assembly and was then towed through the water as the truck was driven across the bridge at a slow, nearly constant, speed. Where piers were inset from the upstream side of the bridge, a flotation device was used to allow the flow to drag the transducer close to the upstream side of the pier. During low to medium flows, the transducer was attached at or near the bow of a boat, which then traversed the cross section or longitudinal profile.

Bed samples were collected to characterize the streambed composition. They were collected primarily during low-flow conditions and are assumed to be representative of high-flow conditions. Sites generally were sampled at three cross sections through a channel reach of at least one bridge length upstream of the site. For some sites, bed-sample information was obtained from MDOT soils reports or from nearby sampled sites on the same stream, where bed conditions were considered to be similar.

Ground-penetrating radar was used for inspection of subsurface bed material. Gorin and Haeni (1989) determined that data from ground-penetrating radar are generally useable for shallow water conditions, but are limited by the depth of water and the

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[1]The use of trade or product names in this report is for identification purposes only and does not constitute endorsement by the USGS.

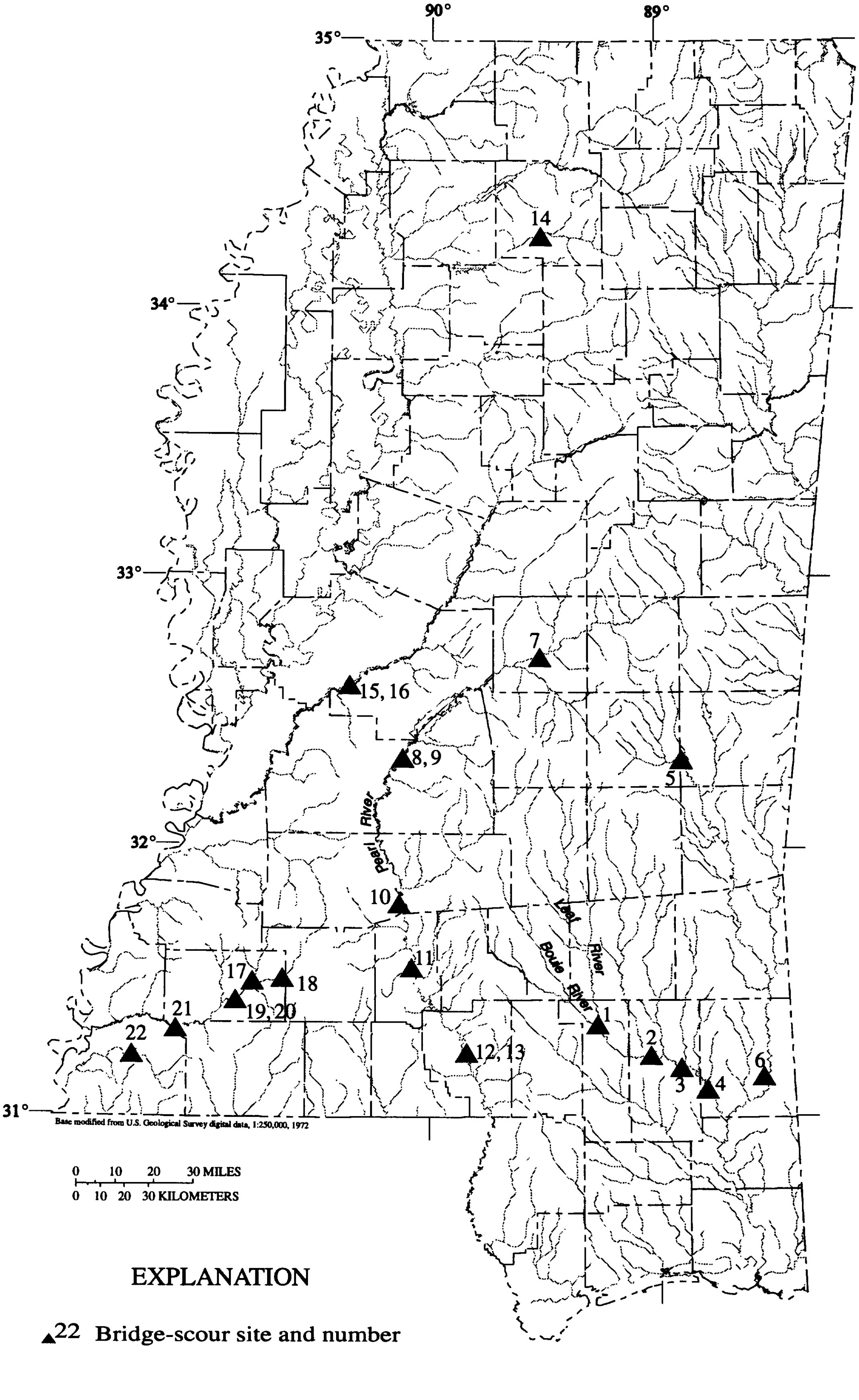


**Figure 1.** Location of bridge-scour sites in Mississippi.

electromagnetic and physical properties of subsurface sediments and water. Ground-penetrating radar was used both in the water and in dry streambeds during low stages to detect scour holes filled by post-scour sediment and to detect subsurface bed material possibly inhibiting scour at a bridge site.

### Description of Bridge-scour Sites

Scour data presented in this report were collected at 22 selected bridge sites in Mississippi (fig. 1). The drainage area of the bridge-scour sites ranged from 60.8 to 5,720 mi$^2$, and the slope in the vicinity of each site ranged from 0.00011 to 0.00163 ft/ft (table 1). The bed material at most sites consisted of sand and(or) gravel. In some cases, the sand or gravel was underlain by a clay stratum, which was thought to affect the measured scour depths.

### Acknowledgments

Special appreciation is extended to members of the Mississippi Department of Transportation, Hydraulics Division, who provided bridge plans, inspection records, and other departmental reports. Special appreciation is also extended to members of the Department of Transportation, Soil Mechanics Laboratory, who assisted in the analysis of soil samples, provided soil and foundation reports, and provided valuable input for bed material analyses.

## PIER-SCOUR DATA

Measurements of pier-scour depths obtained during this study by fathometer and sounding weight were combined with soundings from concurrent and(or) historical discharge measurements, which had soundings near the bridge piers. This information provided an approximation of pier-scour depth for 190 pier-scour measurements at 21 of the 22 sites (tables 2,3). Of the 121 pier-scour measurements obtained since 1990, 112 were obtained with a fathometer, and 9 were obtained with a sounding weight. Of the 69 pier-scour measurements obtained prior to 1990, all but five were determined from selected discharge measurements. Three of the five were pier-scour measurements obtained in 1989 at site 21, where upstream and downstream sides of the bridge were sounded. The remaining two pier-scour measurements were obtained in 1972 and 1973 by a scour-monitoring device installed at site 17 by Hopkins and others (1975, 1980) for the FHWA.

Both upstream and downstream sides of the bridge were usually sounded with the fathometer. The upstream and downstream pier-scour depths were compared for each pier, and the maximum pier-scour depth is presented in this report. By contrast, the pier-scour depths taken from the discharge measurements were limited to one side of the bridge and were not solely obtained on the downstream side of the bridge. The pier-scour depths were determined using an approximation of concurrent ambient bed level as described by Blodgett (1989) and Landers and Mueller (1993). Concurrent ambient bed level is representative of the typical bed elevation adjacent to the scour hole at the time of the measurement. Therefore, it is the elevation representing the streambed at the pier location without any pier scour. Each pier-scour measurement was assigned an approximate accuracy based on measuring conditions at a site. Assigned accuracy ranged from 0.5 ft for a fathometer for favorable conditions to 3 ft for a sounding weight under less favorable conditions. Measurement accuracy was adversely affected by sounding weight drift due to flow, turbulence of the flow, presence of debris piles, and the determination of concurrent ambient bed level.

**Table 1.** Selected bridge sites in Mississippi where scour data were collected
[$mi^2$, square miles; ft/ft, feet per foot]

| Site no. | Station no. | Site name and location | Drainage area ($mi^2$) | Slope in vicinity (ft/ft) |
|---|---|---|---|---|
| 1 | 02473000 | Leaf River at U.S. Highway 11 at Hattiesburg, Miss. | 1,750 | 0.00040 |
| 2 | 02474560 | Leaf River at State Highway 29 near New Augusta, Miss. | 2,540 | 0.00013 |
| 3 | 02474740 | Leaf River at old State Highway 15 at Beaumont, Miss. | 3,010 | 0.00019 |
| 4 | 02475000 | Leaf River at U.S. Highway 98 near McLain, Miss. | 3,500 | 0.00011 |
| 5 | 02475500 | Chunky River at U.S. Highway 80 near Chunky, Miss. | 369 | 0.00051 |
| 6 | 02478500 | Chickasawhay River at State Highway 63 at Leakesville, Miss. | 2,690 | 0.00025 |
| 7 | 02482550 | Pearl River at old State Highway 35 near Carthage, Miss. | 1,350 | 0.00034 |
| 8 | 02485735 | Pearl River at westbound State Highway 25 at Jackson,Miss. | 3,130 | 0.00019 |
| 9 | 02485735 | Pearl River at eastbound State Highway 25 at Jackson, Miss. | 3,130 | 0.00019 |
| 10 | 02488000 | Pearl River at county road bridge at Rockport, Miss. | 4,560 | 0.00015 |
| 11 | 02488500 | Pearl River at U.S. Highway 84 near Monticello, Miss. | 4,990 | 0.00011 |
| 12 | 02489000 | Pearl River at westbound U.S. Highway 98 near Columbia, Miss. | 5,720 | 0.00019 |
| 13 | 02489000 | Pearl River at eastbound U.S. Highway 98 near Columbia, Miss. | 5,720 | 0.00019 |
| 14 | 07274000 | Yocona River at State Highway 7 near Oxford, Miss. | 254 | 0.00062 |
| 15 | 07289730 | Big Black River at northbound U.S. Highway 49 near Bentonia, Miss. | 2,340 | 0.00019 |
| 16 | 07289730 | Big Black River at southbound U.S. Highway 49 near Bentonia, Miss. | 2,340 | 0.00019 |
| 17 | 07291000 | Homochitto River at U.S. Highway 84 at Eddiceton, Miss. | 181 | 0.00093 |
| 18 | 07291250 | McCall Creek at U.S. Highway 84 near Lucien, Miss. | 60.8 | 0.00163 |
| 19 | 07291500 | Homochitto River at old U.S. Highway 98 near Bude, Miss. | 407 | 0.00083 |
| 20 | 07291500 | Homochitto River at U.S. Highway 98 near Bude, Miss. | 407 | 0.00083 |
| 21 | 07292500 | Homochitto River at State Highway 33 at Rosetta, Miss. | 787 | 0.00100 |
| 22 | 07295000 | Buffalo River at old U.S. Highway 61 near Woodville, Miss. | 180 | 0.00059 |

**Table 2.** Summary of stage and discharge data at selected bridge sites in Mississippi
[ft, feet; ft$^3$/s, cubic feet per second; <, less than]

| Station no. | Date | Time (24-hour) | Stage (ft) | Discharge (ft$^3$/s) | Recurrence interval (years) |
|---|---|---|---|---|---|
| 1 | 02-19-90 | 0915 | 145.2 | 54,500 | 10 |
| 2 | 01-27-90 | 1930 | 99.4 | 45,400 | 6 |
| 2 | 02-12-90 | 1630 | 88.4 | 15,800 | <2 |
| 2 | 02-20-90 | 1010 | 101.9 | 65,900 | 15 |
| 3 | 03-23-43 | 1130 | 86.3 | 85,100 | 20 |
| 3 | 01-28-90 | 1745 | 83.0 | 56,400 | 5 |
| 3 | 01-30-90 | 1000 | 82.9 | 55,700 [a] | 5 |
| 3 | 02-01-90 | 1500 | 79.3 | 32,000 [a] | 2 |
| 3 | 02-20-90 | 1600 | 83.8 | 62,400 [a] | 7 |
| 3 | 02-21-90 | 1010 | 84.3 | 66,100 | 8 |
| 4 | 01-29-90 | 1000 | 67.1 | 53,700 [a] | 4 |
| 4 | 02-13-90 | 1400 | 59.7 | 20,400 [a] | <2 |
| 4 | 02-21-90 | 1430 | 68.1 | 68,700 | 8 |
| 6 | 02-23-90 | 1505 | 82.1 | 45,200 | 8 |
| 7 | 04-07-77 | 1135 | 39.5 | 29,600 | 9 |
| 7 | 04-14-79 | 1025 | 343.5 | 90,000 | 500 |
| 7 | 04-16-79 | 1130 | 341.7 | 64,700 | 120 |
| 7 | 04-17-79 | 1245 | 340.0 | 41,400 | 25 |
| 7 | 04-18-79 | 1200 | 338.7 | 24,800 | 6 |
| 7 | 04-19-79 | 1135 | 337.3 | 16,000 | 3 |
| 7 | 03-09-83 | 1255 | 339.5 | 31,300 | 10 |
| 7 | 05-22-83 | 1150 | 342.3 | 68,300 | 150 |
| 7 | 05-23-83 | 1345 | 341.5 | 55,600 | 65 |
| 7 | 01-09-90 | 1525 | 337.5 | 15,800 | 2 |
| 7 | 02-22-91 | 1245 | 337.4 | 17,200 | 3 |
| 7 | 04-18-91 | 1500 | 338.6 | 25,100 | 6 |
| 7 | 05-02-91 | 1425 | 339.7 | 32,800 | 10 |
| 8 | 01-31-90 | 1500 | 267.0 | 22,500 [a] | <2 |
| 8 | 02-25-91 | 1500 | 271.4 | 36,800 | 3 |
| 8 | 05-01-91 | 1110 | 273.6 | 49,800 | 7 |
| 9 | 02-25-91 | 1500 | 271.4 | 36,800 | 3 |
| 9 | 05-01-91 | 1110 | 273.6 | 49,800 | 7 |
| 10 | 05-03-91 | 1000 | 214.6 | 59,000 | 10 |
| 11 | 01-26-90 | 1000 | 187.5 | 68,400 | 15 |
| 11 | 02-14-90 | 1500 | 182.8 | 35,900 [a] | 2 |

**Table 2.** Summary of stage and discharge data at selected bridge sites in Mississippi--Continued

| Station no. | Date | Time (24-hour) | Stage (ft) | Discharge ($ft^3/s$) | Recurrence interval (years) |
|---|---|---|---|---|---|
| 11 | 04-23-91 | 0935 | 185.8 | 51,200 | 5 |
| 11 | 05-06-91 | 1255 | 188.0 | 71,400 | 20 |
| 12 | 01-27-90 | 1335 | 140.4 | 73,000 | 20 |
| 12 | 01-30-90 | 1500 | 139.1 | 61,000 [a] | 10 |
| 12 | 02-05-90 | 1735 | 134.7 | 42,000 [a] | 3 |
| 12 | 05-10-91 | 1320 | 140.4 | 71,700 | 20 |
| 13 | 01-27-90 | 1335 | 140.4 | 73,000 | 20 |
| 13 | 01-30-90 | 1500 | 139.1 | 61,000 [a] | 10 |
| 13 | 05-10-91 | 1320 | 140.4 | 71,700 | 20 |
| 14 | 02-19-91 | 1900 | 295.2 | 24,300 | 10 |
| 15 | 02-24-91 | 1600 | 158.9 | 41,600 | 5 |
| 15 | 05-02-91 | 1100 | 159.6 | 47,100 | 7 |
| 16 | 02-24-91 | 1600 | 158.9 | 41,600 | 5 |
| 16 | 05-02-91 | 1100 | 159.6 | 47,100 | 7 |
| 17 | 04-25-72 | 0530 | 226.0 | 8,300 [a] | <2 |
| 17 | 12-21-72 | 0600 | 230.6 | 18,400 [a] | 2 |
| 17 | 01-25-90 | 0900 | 228.2 | 14,900 | <2 |
| 17 | 08-27-92 | 0930 | 227.7 | 13,400 | <2 |
| 18 | 04-29-53 | 1650 | 293.1 | 5,360 | <2 |
| 18 | 12-17-59 | 1145 | 292.0 | 4,900 | <2 |
| 18 | 03-28-61 | 1120 | 299.1 | 17,900 | 15 |
| 18 | 09-16-71 | 1700 | 289.2 | 1,880 | <2 |
| 18 | 12- 6-71 | 1140 | 295.4 | 12,500 | 5 |
| 18 | 04-13-74 | 1510 | 300.8 | 22,400 | 50 |
| 18 | 07-02-81 | 1110 | 292.7 | 8,640 | 2 |
| 18 | 01-25-90 | 1730 | 290.0 | 6,140 | <2 |
| 19 | 12-27-42 | 1800 | 196.5 | 22,200 | <2 |
| 19 | 04-01-47 | 2400 | 198.7 | 32,100 | 2 |
| 19 | 04-11-47 | 1440 | 196.8 | 23,700 | <2 |
| 20 | 12-06-71 | 1650 | 203.0 | 61,100 | 15 |
| 21 | 11-30-77 | 1200 | 113.3 | 46,500 | <2 |
| 21 | 08-29-78 | 1735 | 112.7 | 39,500 | <2 |
| 21 | 03-28-80 | 1330 | 111.4 | 30,700 | <2 |
| 21 | 12-04-82 | 1235 | 114.8 | 64,000 | 2 |
| 21 | 02-01-83 | 1500 | 112.5 | 33,800 | <2 |

**Table 2.** Summary of stage and discharge data at selected bridge sites in Mississippi--Continued

| Station no. | Date | Time (24-hour) | Stage (ft) | Discharge ($ft^3/s$) | Recurrence interval (years) |
|---|---|---|---|---|---|
| 21 | 04-06-83 | 1245 | 112.1 | 36,500 | <2 |
| 21 | 10-23-84 | 1040 | 112.1 | 33,900 | <2 |
| 21 | 05-19-89 | 1210 | 112.6 | 45,300 | <2 |
| 21 | 01-25-90 | 1625 | 111.5 | 31,500 | <2 |
| 21 | 02-16-90 | 1450 | 108.8 | 20,100 | <2 |
| 21 | 11-15-93 | 1640 | 110.6 | 33,300 | <2 |
| 21 | 01-28-94 | 0820 | 115.6 | 74,300 | 3 |
| 22 | 03-03-48 | 0950 | 106.6 | 8,800 | <2 |
| 22 | 01-06-50 | 1130 | 109.3 | 20,100 | 2 |
| 22 | 05-18-53 | 0745 | 106.9 | 11,500 | <2 |
| 22 | 03-28-61 | 1545 | 110.4 | 22,500 | 2 |
| 22 | 10-04-64 | 1735 | 112.7 | 34,400 | 3 |
| 22 | 08-04-75 | 1840 | 104.8 | 4,710 | <2 |
| 22 | 04-21-77 | 1410 | 111.8 | 34,000 | 3 |
| 22 | 04-22-79 | 1730 | 113.5 | 37,000 | 4 |
| 22 | 04-06-83 | 1510 | 109.5 | 13,500 | <2 |
| 22 | 03-31-88 | 1840 | 106.9 | 13,500 | <2 |
| 22 | 01-24-90 | 1700 | 114.6 | 41,900 | 6 |

[a] Discharge determined from stage-discharge relation. Total discharge not measured.

**Table 3.** Pier-scour data collected at selected bridge sites in Mississippi

[no., number; ID, identification; Loc., location; ft, feet; Acc., accuracy; $D_{50}$; median diameter; $\sigma_g$, gradation coefficient; ft/s, feet per second; Loc. code: 1, upstream side of bridge; 2, downstream side of bridge; --, no data]

| Bridge site no. | Measurement no. | Pier ID | Date | Time (24-hour) | Loc. code | Measured pier scour | | | Bed material | | Pier geometry | | | | | Approach flow | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Depth (ft) | Acc. (ft) | Width (ft) | $D_{50}$ (ft) | $\sigma_g$ | Type | Shape | Width (ft) | Length (ft) | Normal width (ft) | Depth (ft) | Velocity (ft/s) | Skew (degrees) |
| 1 | 1 | 3 | 02-19-90 | 1725 | 2 | 2.2 | 1.0 | 32 | 0.00121 | 2.6 | group | cylinder | 4.0 | 71.5 | 16.0 | 32.2 | 7.0 | 11 |
| 2 | 2 | A | 01-27-90 | 1815 | 2 | 8.2 | 1.0 | 100 | .00492 | 6.9 | group | cylinder | 4.0 | 24.0 | 4.0 | 29.3 | 4.9 | 0 |
| 2 | 3 | A | 02-12-90 | 1440 | 2 | 6.0 | 1.0 | 40 | .00492 | 6.9 | group | cylinder | 4.0 | 24.0 | 4.0 | 18.7 | 4.0 | 0 |
| 2 | 4 | A | 02-20-90 | 1220 | 2 | 7.5 | 0.5 | 96 | .00492 | 6.9 | group | cylinder | 4.0 | 24.0 | 4.0 | 32.4 | 5.6 | 0 |
| 2 | 5 | B | 01-27-90 | 1800 | 1 | 3.9 | 1.0 | 42 | .00492 | 6.9 | group | cylinder | 4.0 | 24.0 | 4.0 | 28.4 | 5.9 | 0 |
| 2 | 6 | B | 02-12-90 | 1710 | 1 | 3.9 | 1.0 | 34 | .00492 | 6.9 | group | cylinder | 4.0 | 24.0 | 4.0 | 16.7 | 4.5 | 0 |
| 2 | 7 | B | 02-20-90 | 1300 | 1 | 5.4 | 0.5 | 55 | .00492 | 6.9 | group | cylinder | 4.0 | 24.0 | 4.0 | 30.6 | 7.0 | 0 |
| 3 | 8 | 1 | 01-28-90 | 1540 | 1 | 2.4 | 0.5 | 10 | .00118 | 4.3 | single | square | 2.8 | 22.5 | 5.9 | 25.7 | 4.7 | 8 |
| 3 | 9 | 1 | 02-20-90 | 1620 | 1 | 2.5 | 0.5 | 8 | .00118 | 4.3 | single | square | 2.8 | 22.5 | 7.0 | 25.9 | 4.9 | 11 |
| 3 | 10 | 1 | 02-21-90 | 0840 | 1 | 1.3 | 0.5 | 8 | .00118 | 4.3 | single | square | 2.8 | 22.5 | 7.0 | 27.1 | 5.3 | 11 |
| 3 | 11 | 2 | 03-23-43 | 1130 | 1 | 5.9 | 1.0 | -- | .00118 | 4.3 | single | square | 3.5 | 23.0 | 3.5 | 36.6 | 10.3 | 0 |
| 3 | 12 | 2 | 01-28-90 | 1540 | 1 | 4.0 | 0.5 | -- | .00118 | 4.3 | single | square | 3.3 | 23.0 | 9.5 | 28.2 | 7.3 | 16 |
| 3 | 13 | 2 | 02-20-90 | 1620 | 1 | 0.8 | 0.5 | 11 | .00118 | 4.3 | single | square | 3.4 | 23.0 | 7.7 | 31.4 | 7.7 | 11 |
| 3 | 14 | 2 | 02-21-90 | 0840 | 1 | 1.1 | 0.5 | 16 | .00118 | 4.3 | single | square | 3.2 | 23.0 | 7.5 | 31.0 | 7.9 | 11 |
| 3 | 15 | 3 | 03-23-43 | 1130 | 1 | 3.8 | 1.0 | -- | .00118 | 4.3 | single | square | 3.2 | 23.0 | 3.2 | 34.3 | 8.8 | 0 |
| 3 | 16 | 3 | 01-28-90 | 1540 | 1 | 8.8 | 0.5 | 58 | .00118 | 4.3 | single | square | 3.2 | 23.0 | 8.7 | 23.1 | 7.8 | 14 |
| 3 | 17 | 3 | 01-28-90 | 1720 | 1 | 7.6 | 1.0 | -- | .00118 | 4.3 | single | square | 3.2 | 23.0 | 8.7 | 25.8 | 7.8 | 14 |
| 3 | 18 | 3 | 01-30-90 | 0955 | 2 | 5.9 | 0.5 | 61 | .00118 | 4.3 | single | square | 3.2 | 23.0 | 8.7 | 28.6 | 7.8 | 14 |
| 3 | 19 | 3 | 02-01-90 | 1430 | 1 | 4.6 | 0.5 | 24 | .00118 | 4.3 | single | square | 3.2 | 23.0 | 7.5 | 23.1 | 3.3 | 11 |
| 3 | 20 | 3 | 02-20-90 | 1620 | 1 | 4.8 | 0.5 | 31 | .00118 | 4.3 | single | square | 3.2 | 23.0 | 7.5 | 28.1 | 8.1 | 11 |
| 3 | 21 | 3 | 02-21-90 | 0840 | 1 | 6.7 | 0.5 | 46 | .00118 | 4.3 | single | square | 3.2 | 23.0 | 6.4 | 26.6 | 6.9 | 8 |
| 3 | 22 | 3 | 02-21-90 | 1100 | 1 | 9.3 | 1.0 | 70 | .00118 | 4.3 | single | square | 3.2 | 23.0 | 6.4 | 29.7 | 6.9 | 8 |
| 3 | 23 | 4 | 01-28-90 | 1540 | 1 | 7.3 | 0.5 | 44 | .00118 | 4.3 | single | square | 2.8 | 22.5 | 7.0 | 23.0 | 6.1 | 11 |
| 3 | 24 | 4 | 01-28-90 | 1940 | 1 | 2.9 | 1.0 | 25 | .00118 | 4.3 | single | square | 2.8 | 22.5 | 7.0 | 26.8 | 6.1 | 11 |
| 3 | 25 | 4 | 01-30-90 | 0925 | 1 | 2.2 | 0.5 | 16 | .00118 | 4.3 | single | square | 2.8 | 22.5 | 7.0 | 27.0 | 6.1 | 11 |
| 3 | 26 | 4 | 02-01-90 | 1430 | 1 | 1.7 | 0.5 | 11 | .00118 | 4.3 | single | square | 2.8 | 22.5 | 8.2 | 24.0 | 3.3 | 14 |
| 3 | 27 | 4 | 02-20-90 | 1620 | 1 | 3.0 | 0.5 | 20 | .00118 | 4.3 | single | square | 2.8 | 22.5 | 7.0 | 29.1 | 5.8 | 11 |
| 3 | 28 | 4 | 02-21-90 | 0840 | 1 | 4.1 | 0.5 | 25 | .00118 | 4.3 | single | square | 2.8 | 22.5 | 7.0 | 28.2 | 6.8 | 11 |

**Table 3.** Pier-scour data collected at selected bridge sites in Mississippi--**Continued**

| Bridge site no. | Measurement no. | Pier ID | Date | Time (24-hour) | Loc. code | Measured pier scour Depth (ft) | Measured pier scour Acc. (ft) | Measured pier scour Width (ft) | Bed material $D_{50}$ (ft) | Bed material $\sigma_g$ | Pier geometry Type | Pier geometry Shape | Pier geometry Width (ft) | Pier geometry Length (ft) | Pier geometry Normal width (ft) | Approach flow Depth (ft) | Approach flow Velocity (ft/s) | Approach flow Skew (degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4 | 29 | 1 | 01-29-90 | 0930 | 1 | 8.6 | 1.0 | 36 | 0.00092 | 1.7 | single | sharp | 2.9 | 26.2 | 8.9 | 9.7 | 3.5 | 14 |
| 4 | 30 | 1 | 02-21-90 | 1620 | 1 | 5.4 | 1.0 | 34 | .00092 | 1.7 | single | sharp | 3.0 | 26.2 | 11.8 | 13.5 | 4.5 | 20 |
| 4 | 31 | 2 | 01-29-90 | 0945 | 2 | 3.0 | 1.0 | 31 | .00092 | 1.7 | single | sharp | 3.4 | 26.9 | 13.6 | 29.4 | 7.8 | 23 |
| 4 | 32 | 2 | 02-13-90 | 1405 | 2 | 6.9 | 0.5 | 41 | .00092 | 1.7 | single | sharp | 3.4 | 26.9 | 8.5 | 16.8 | 4.2 | 11 |
| 4 | 33 | 2 | 02-21-90 | 1620 | 1 | 7.4 | 1.0 | 83 | .00092 | 1.7 | single | sharp | 3.3 | 26.9 | 3.3 | 27.6 | 7.6 | 0 |
| 4 | 34 | 3 | 01-29-90 | 0945 | 2 | 4.5 | 1.0 | 50 | .00092 | 1.7 | single | sharp | 3.3 | 26.9 | 12.3 | 25.4 | 4.7 | 20 |
| 4 | 35 | 3 | 02-13-90 | 1405 | 2 | 5.9 | 0.5 | 62 | .00092 | 1.7 | single | sharp | 3.5 | 26.9 | 9.9 | 20.0 | 3.1 | 14 |
| 4 | 36 | 3 | 02-21-90 | 1555 | 2 | 2.5 | 1.0 | 52 | .00092 | 1.7 | single | sharp | 3.3 | 26.9 | 12.3 | 29.3 | 4.9 | 20 |
| 4 | 37 | 4 | 01-29-90 | 0945 | 2 | 4.6 | 1.0 | 55 | .00092 | 1.7 | single | sharp | 3.2 | 26.2 | 12.0 | 21.8 | 1.4 | 20 |
| 4 | 38 | 4 | 02-21-90 | 1555 | 2 | 3.4 | 1.0 | 55 | .00092 | 1.7 | single | sharp | 3.2 | 26.2 | 12.0 | 24.8 | 1.4 | 20 |
| 6 | 39 | 2 | 02-23-90 | 1420 | 1 | 1.5 | 1.0 | 39 | .00095 | 1.5 | single | square | 7.2 | 26.0 | 7.2 | 32.1 | 3.5 | 0 |
| 6 | 40 | 3 | 02-23-90 | 1510 | 2 | 2.5 | 1.0 | 30 | .00095 | 1.5 | single | square | 5.8 | 26.0 | 5.8 | 25.1 | 2.5 | 0 |
| 7 | 41 | 1 | 04-07-77 | 1105 | 2 | 4.0 | 2.0 | 45 | .00102 | 1.8 | single | round | 3.9 | 32.0 | 3.9 | 20.3 | 2.8 | 0 |
| 7 | 42 | 1 | 04-14-79 | 1010 | 2 | 10.5 | 2.0 | 70 | .00102 | 1.8 | single | round | 4.0 | 32.1 | 12.7 | 24.0 | 5.0 | 16 |
| 7 | 43 | 1 | 04-16-79 | 1125 | 2 | 12.9 | 2.0 | 50 | .00102 | 1.8 | single | round | 4.0 | 32.1 | 14.7 | 26.5 | 4.6 | 20 |
| 7 | 44 | 1 | 04-17-79 | 1245 | 2 | 8.0 | 2.0 | 65 | .00102 | 1.8 | single | round | 4.0 | 32.1 | 14.7 | 23.5 | 4.4 | 20 |
| 7 | 45 | 1 | 04-18-79 | 1150 | 2 | 7.0 | 2.0 | 60 | .00102 | 1.8 | single | round | 4.0 | 32.2 | 14.8 | 23.0 | 3.7 | 20 |
| 7 | 46 | 1 | 04-19-79 | 1125 | 2 | 5.8 | 2.0 | 75 | .00102 | 1.8 | single | round | 4.1 | 32.2 | 20.3 | 21.5 | 3.0 | 32 |
| 7 | 47 | 1 | 03-09-83 | 1225 | 2 | 10.0 | 2.0 | 85 | .00102 | 1.8 | single | round | 5.2 | 32.8 | 19.1 | 27.0 | 3.9 | 26 |
| 7 | 48 | 1 | 05-22-83 | 1140 | 2 | 11.5 | 2.0 | 115 | .00102 | 1.8 | single | round | 5.0 | 32.7 | 16.9 | 29.5 | 5.3 | 22 |
| 7 | 49 | 1 | 05-23-83 | 1345 | 2 | 10.8 | 2.0 | 130 | .00102 | 1.8 | single | round | 5.0 | 32.7 | 11.1 | 28.6 | 3.1 | 11 |
| 7 | 50 | 1 | 01-09-90 | 1500 | 2 | 7.2 | 2.0 | 75 | .00102 | 1.8 | single | round | 6.4 | 33.5 | 12.7 | 28.6 | 3.9 | 11 |
| 7 | 51 | 1 | 02-22-91 | 1305 | 2 | 6.8 | 2.0 | 65 | .00102 | 1.8 | single | round | 6.7 | 33.7 | 13.0 | 30.0 | 3.8 | 11 |
| 7 | 52 | 1 | 04-18-91 | 1450 | 2 | 6.5 | 2.0 | 65 | .00102 | 1.8 | single | round | 6.5 | 33.6 | 16.6 | 31.0 | 4.0 | 18 |
| 7 | 53 | 1 | 05-02-91 | 1425 | 2 | 6.4 | 2.0 | 85 | .00102 | 1.8 | single | round | 6.4 | 33.6 | 12.6 | 32.0 | 3.7 | 8 |
| 8 | 54 | 12L | 02-25-91 | 1430 | 1 | 2.0 | 0.5 | 16 | -- | -- | group | square | 1.3 | 26.3 | 9.0 | 9.6 | 2.5 | 28 |
| 8 | 55 | 12L | 05-01-91 | 1000 | 2 | 2.5 | 0.5 | 18 | -- | -- | group | square | 1.3 | 26.3 | 8.7 | 16.7 | 2.8 | 23 |
| 8 | 56 | 13L | 02-25-91 | 1430 | 1 | 6.7 | 0.5 | 38 | -- | -- | group | square | 1.3 | 26.3 | 8.7 | 13.2 | 3.3 | 23 |
| 8 | 57 | 13L | 05-01-91 | 1000 | 1 | 4.9 | 0.5 | 32 | -- | -- | group | square | 1.3 | 26.3 | 8.4 | 16.0 | 3.4 | 18 |
| 8 | 58 | 15L | 02-25-91 | 1430 | 1 | 1.3 | 0.5 | 20 | .00177 | 1.8 | group | square | 1.3 | 26.3 | 8.2 | 29.2 | 3.8 | 16 |

**Table 3.** Pier-scour data collected at selected bridge sites in Mississippi--**Continued**

| Bridge site no. | Measure-ment no. | Pier ID | Date | Time (24-hour) | Loc. code | Measured pier scour Depth (ft) | Measured pier scour Acc. (ft) | Measured pier scour Width (ft) | Bed material $D_{50}$ (ft) | Bed material $\sigma_g$ | Pier geometry Type | Pier geometry Shape | Pier geometry Width (ft) | Pier geometry Length (ft) | Pier geometry Normal width (ft) | Approach flow Depth (ft) | Approach flow Velocity (ft/s) | Approach flow Skew (degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | 59 | 15L | 05-01-91 | 1000 | 2 | 3.0 | 0.5 | 40 | 0.00177 | 1.8 | group | square | 1.3 | 26.3 | 8.1 | 29.0 | 4.4 | 14 |
| 8 | 60 | 16L | 02-25-91 | 1430 | 1 | 1.4 | 0.5 | 23 | .00177 | 1.8 | group | square | 2.7 | 26.3 | 9.8 | 29.0 | 4.0 | 16 |
| 8 | 61 | 16L | 05-01-91 | 1000 | 1 | 1.4 | 0.5 | 24 | .00177 | 1.8 | group | square | 2.7 | 26.3 | 6.3 | 26.9 | 4.7 | 8 |
| 8 | 62 | 17L | 01-31-90 | 1500 | 1 | 2.0 | 0.5 | 25 | .00128 | 1.9 | group | cylinder | 5.8 | 22.8 | 10.0 | 17.5 | 2.8 | 11 |
| 8 | 63 | 17L | 02-25-91 | 1430 | 1 | 3.6 | 0.5 | 41 | .00128 | 1.9 | group | cylinder | 5.4 | 22.4 | 10.2 | 22.0 | 3.4 | 16 |
| 8 | 64 | 17L | 05-01-91 | 1000 | 1 | 4.1 | 0.5 | 41 | .00128 | 1.9 | group | cylinder | 4.7 | 21.6 | 8.2 | 21.4 | 3.5 | 11 |
| 8 | 65 | 18L | 01-31-90 | 1500 | 1 | 1.6 | 0.5 | 19 | .00128 | 1.9 | group | cylinder | 5.8 | 22.7 | 9.9 | 17.4 | 1.3 | 11 |
| 8 | 66 | 18L | 02-25-91 | 1430 | 1 | 2.0 | 0.5 | 21 | .00128 | 1.9 | group | cylinder | 5.3 | 22.1 | 9.8 | 21.1 | 1.9 | 16 |
| 8 | 67 | 18L | 05-01-91 | 1000 | 2 | 2.6 | 0.5 | 18 | .00128 | 1.9 | group | cylinder | 4.9 | 21.7 | 9.0 | 22.3 | 2.2 | 14 |
| 9 | 68 | 12R | 02-25-91 | 1520 | 1 | 4.5 | 0.5 | 50 | -- | -- | group | square | 1.3 | 26.3 | 8.7 | 10.8 | 3.1 | 23 |
| 9 | 69 | 12R | 05-01-91 | 1120 | 1 | 4.3 | 0.5 | 40 | -- | -- | group | square | 1.3 | 26.3 | 8.5 | 13.8 | 3.3 | 20 |
| 9 | 70 | 13R | 02-25-91 | 1520 | 1 | 4.6 | 0.5 | 19 | -- | -- | group | square | 1.3 | 26.3 | 8.7 | 12.5 | 3.4 | 22 |
| 9 | 71 | 13R | 05-01-91 | 1120 | 1 | 3.8 | 0.5 | 28 | -- | -- | group | square | 1.3 | 26.3 | 8.2 | 14.6 | 3.9 | 16 |
| 9 | 72 | 15R | 05-01-91 | 1120 | 1 | 1.4 | 0.5 | 20 | .00177 | 1.8 | group | square | 1.3 | 26.3 | 8.2 | 30.6 | 5.1 | 16 |
| 9 | 73 | 16R | 02-25-91 | 1520 | 1 | 2.9 | 0.5 | 19 | .00177 | 1.8 | group | square | 2.7 | 26.3 | 9.8 | 27.5 | 3.9 | 16 |
| 9 | 74 | 16R | 05-01-91 | 1120 | 1 | 2.1 | 0.5 | 26 | .00177 | 1.8 | group | square | 2.7 | 26.3 | 7.6 | 26.6 | 4.7 | 11 |
| 9 | 75 | 17R | 02-25-91 | 1520 | 1 | 1.6 | 0.5 | 27 | .00128 | 1.9 | group | cylinder | 5.5 | 22.6 | 10.6 | 23.3 | 2.8 | 16 |
| 9 | 76 | 17R | 05-01-91 | 1120 | 1 | 3.9 | 0.5 | 28 | .00128 | 1.9 | group | cylinder | 4.8 | 21.6 | 7.4 | 21.7 | 3.2 | 8 |
| 9 | 77 | 18R | 02-25-91 | 1520 | 1 | 5.7 | 0.5 | 31 | .00128 | 1.9 | group | cylinder | 5.1 | 21.9 | 9.7 | 20.2 | 2.4 | 20 |
| 9 | 78 | 18R | 05-01-91 | 1120 | 1 | 3.7 | 0.5 | 26 | .00128 | 1.9 | group | cylinder | 5.1 | 21.9 | 9.2 | 23.0 | 2.0 | 14 |
| 10 | 79 | 4 | 05-03-91 | 1220 | 1 | 4.8 | 0.5 | 80 | -- | -- | group | cylinder | 4.5 | 21.8 | 4.5 | 32.5 | 6.3 | 0 |
| 11 | 80 | 2 | 01-26-90 | 1135 | 2 | 3.6 | 1.0 | 28 | .00125 | 1.8 | single | square | 3.9 | 26.0 | 12.6 | 28.0 | 5.1 | 20 |
| 11 | 81 | 2 | 02-14-90 | 1520 | 2 | 1.7 | 0.5 | 23 | .00125 | 1.8 | single | square | 4.0 | 26.0 | 8.9 | 28.0 | 3.7 | 11 |
| 11 | 82 | 2 | 04-23-91 | 1120 | 2 | 3.6 | 0.5 | 21 | .00125 | 1.8 | single | square | 4.0 | 26.0 | 4.0 | 24.4 | 4.3 | 0 |
| 11 | 83 | 2 | 05-06-91 | 1150 | 1 | 3.7 | 0.5 | 32 | .00125 | 1.8 | single | square | 3.9 | 26.0 | 10.9 | 26.3 | 4.4 | 16 |
| 11 | 84 | 3 | 01-26-90 | 0845 | 1 | 6.1 | 0.5 | 112 | .00125 | 1.8 | single | square | 4.0 | 26.0 | 7.6 | 32.1 | 7.2 | 8 |
| 11 | 85 | 3 | 02-14-90 | 1520 | 2 | 7.5 | 0.5 | 146 | .00125 | 1.8 | single | square | 4.0 | 26.0 | 4.0 | 27.2 | 5.3 | 0 |
| 11 | 86 | 3 | 04-23-91 | 1155 | 1 | 8.2 | 1.0 | 111 | .00125 | 1.8 | single | square | 4.0 | 26.0 | 7.6 | 30.2 | 6.4 | 8 |
| 11 | 87 | 3 | 05-06-91 | 1150 | 1 | 7.9 | 1.0 | 99 | .00125 | 1.8 | single | square | 3.9 | 26.0 | 10.9 | 32.9 | 8.1 | 16 |
| 12 | 88 | 6 | 01-27-90 | 1455 | 1 | 4.9 | 0.5 | 46 | .02264 | 6.2 | group | cylinder | 5.5 | 22.8 | 10.5 | 30.1 | 5.6 | 16 |

**Table 3.** Pier-scour data collected at selected bridge sites in Mississippi--**Continued**

| Bridge site no. | Measurement no. | Pier ID | Date | Time (24-hour) | Loc. code | Measured pier scour Depth (ft) | Measured pier scour Acc. (ft) | Measured pier scour Width (ft) | Bed material $D_{50}$ (ft) | Bed material $\sigma_g$ | Pier geometry Type | Pier geometry Shape | Pier geometry Width (ft) | Pier geometry Length (ft) | Pier geometry Normal width (ft) | Approach flow Depth (ft) | Approach flow Velocity (ft/s) | Approach flow Skew (degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 12 | 89 | 6 | 01-30-90 | 1500 | 2 | 6.5 | 0.5 | 62 | 0.02264 | 6.2 | group | cylinder | 5.5 | 22.7 | 10.3 | 27.7 | 6.9 | 14 |
| 12 | 90 | 6 | 02-05-90 | 1735 | 2 | 6.6 | 0.5 | 30 | .02264 | 6.2 | group | cylinder | 5.8 | 23.2 | 11.6 | 25.1 | 4.2 | 18 |
| 12 | 91 | 6 | 05-10-91 | 1045 | 1 | 9.9 | 0.5 | 49 | .02264 | 6.2 | group | cylinder | 5.4 | 22.5 | 10.1 | 27.3 | 7.2 | 14 |
| 12 | 92 | 5 | 01-27-90 | 1230 | 1 | 7.5 | 0.5 | 82 | .02264 | 6.2 | group | cylinder | 5.5 | 22.6 | 11.3 | 28.4 | 7.7 | 22 |
| 12 | 93 | 5 | 01-30-90 | 1500 | 1 | 3.3 | 0.5 | 44 | .02264 | 6.2 | group | cylinder | 6.4 | 22.9 | 10.5 | 28.6 | 5.7 | 8 |
| 12 | 94 | 5 | 02-05-90 | 1735 | 1 | 2.0 | 0.5 | 38 | .02264 | 6.2 | group | cylinder | 5.8 | 23.3 | 9.9 | 25.7 | 4.3 | 16 |
| 12 | 95 | 5 | 05-10-91 | 1045 | 2 | 4.5 | 0.5 | 36 | .02264 | 6.2 | group | cylinder | 5.5 | 22.7 | 9.3 | 28.9 | 6.6 | 11 |
| 12 | 96 | 4 | 01-27-90 | 1455 | 1 | 1.9 | 0.5 | 34 | .02264 | 6.2 | group | cylinder | 5.4 | 22.4 | 8.1 | 26.9 | 5.3 | 8 |
| 12 | 97 | 4 | 01-30-90 | 1500 | 1 | 3.2 | 0.5 | 41 | .02264 | 6.2 | group | cylinder | 5.5 | 22.4 | 8.2 | 25.0 | 4.6 | 8 |
| 12 | 98 | 4 | 05-10-91 | 1045 | 1 | 1.4 | 0.5 | 13 | .02264 | 6.2 | group | cylinder | 5.5 | 22.7 | 9.2 | 29.1 | 5.1 | 11 |
| 13 | 99 | 4 | 01-30-90 | 1415 | 2 | 4.8 | 0.5 | 35 | .02264 | 6.2 | single | square | 5.4 | 26.5 | 11.7 | 22.3 | 7.0 | 14 |
| 13 | 100 | 4 | 05-10-91 | 1445 | 1 | 2.3 | 0.5 | 21 | .02264 | 6.2 | single | square | 5.4 | 26.4 | 9.0 | 24.6 | 7.0 | 8 |
| 13 | 101 | 5 | 01-30-90 | 1415 | 1 | 5.3 | 0.5 | 35 | .02264 | 6.2 | single | square | 6.1 | 27.7 | 9.9 | 28.1 | 6.5 | 8 |
| 13 | 102 | 5 | 05-10-91 | 1445 | 2 | 3.9 | 0.5 | 47 | .02264 | 6.2 | single | square | 6.0 | 27.5 | 11.1 | 28.9 | 6.4 | 11 |
| 13 | 103 | 6 | 01-30-90 | 1415 | 1 | 5.7 | 1.0 | 37 | .02264 | 6.2 | single | square | 5.5 | 27.3 | 5.5 | 26.4 | 3.5 | 0 |
| 13 | 104 | 6 | 05-10-91 | 1445 | 2 | 7.4 | 1.0 | 61 | .02264 | 6.2 | single | square | 5.7 | 27.1 | 10.8 | 30.1 | 5.1 | 11 |
| 13 | 105 | 7 | 01-30-90 | 1415 | 1 | 4.1 | 0.5 | 27 | .02264 | 6.2 | group | square | 3.9 | 22.7 | 3.9 | 23.0 | 1.9 | 0 |
| 13 | 106 | 7 | 05-10-91 | 1445 | 2 | 2.5 | 1.0 | 35 | .02264 | 6.2 | group | square | 4.1 | 22.9 | 4.1 | 28.9 | 2.9 | 0 |
| 14 | 107 | B | 02-19-91 | 2000 | 1 | 5.5 | 2.0 | 40 | .00135 | 1.7 | single | cylinder | 10.0 | 10.0 | 10.0 | 24.7 | 5.2 | 24 |
| 15 | 108 | 4R | 02-24-91 | 1505 | 2 | 4.4 | 0.5 | 53 | .00118 | 1.3 | group | square | 5.9 | 41.6 | 15.8 | 29.3 | 4.1 | 14 |
| 15 | 109 | 4R | 05-02-91 | 0925 | 2 | 3.4 | 0.5 | 41 | .00118 | 1.3 | group | square | 5.9 | 41.6 | 17.1 | 29.8 | 4.2 | 16 |
| 15 | 110 | 5R | 02-24-91 | 1505 | 2 | 5.7 | 0.5 | 61 | .00118 | 1.3 | group | square | 6.0 | 41.6 | 13.8 | 28.3 | 5.5 | 11 |
| 15 | 111 | 5R | 05-02-91 | 0925 | 2 | 5.0 | 0.5 | 68 | .00118 | 1.3 | group | square | 5.9 | 41.6 | 13.7 | 29.4 | 4.9 | 11 |
| 16 | 112 | 4L | 02-24-91 | 1715 | 1 | 8.3 | 1.0 | 53 | .00118 | 1.3 | group | square | 5.9 | 41.6 | 17.1 | 29.1 | 5.0 | 16 |
| 16 | 113 | 4L | 05-02-91 | 1045 | 1 | 2.9 | 0.5 | 34 | .00118 | 1.3 | group | square | 5.7 | 41.6 | 15.6 | 32.9 | 5.1 | 14 |
| 16 | 114 | 5L | 02-24-91 | 1730 | 1 | 4.9 | 0.5 | 27 | .00118 | 1.3 | group | square | 5.8 | 41.6 | 13.6 | 32.8 | 5.5 | 11 |
| 16 | 115 | 5L | 05-02-91 | 1110 | 2 | 3.6 | 0.5 | 44 | .00118 | 1.3 | group | square | 5.7 | 41.6 | 13.5 | 33.3 | 4.9 | 11 |
| 17 | 116 | 3 | 01-25-90 | 0900 | 1 | 4.1 | 1.0 | -- | .02464 | 6.9 | single | cylinder | 8.0 | 8.0 | 8.0 | 10.0 | 6.2 | 0 |
| 17 | 117 | 3 | 08-27-92 | 1010 | 2 | 3.2 | 1.0 | 50 | .02464 | 6.9 | single | cylinder | 8.0 | 8.0 | 8.0 | 8.5 | 6.2 | 0 |
| 17 | 118 | 4 | 12-21-72 | 0600 | 1 | 2.9 | 0.5 | -- | .02464 | 6.9 | single | cylinder | 8.0 | 8.0 | 8.0 | 12.9 | 7.0 | 0 |

**Table 3.** Pier-scour data collected at selected bridge sites in Mississippi--**Continued**

| Bridge site no. | Measure-ment no. | Pier ID | Date | Time (24-hour) | Loc. code | Measured pier scour Depth (ft) | Measured pier scour Acc. (ft) | Measured pier scour Width (ft) | Bed material $D_{50}$ (ft) | Bed material $\sigma_g$ | Pier geometry Type | Pier geometry Shape | Pier geometry Width (ft) | Pier geometry Length (ft) | Pier geometry Normal width (ft) | Approach flow Depth (ft) | Approach flow Velocity (ft/s) | Approach flow Skew (degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 17 | 119 | 4 | 04-25-73 | 0530 | 1 | 2.9 | 0.5 | -- | 0.02464 | 6.9 | single | cylinder | 8.0 | 8.0 | 8.0 | 9.0 | 6.1 | 0 |
| 17 | 120 | 4 | 01-25-90 | 0900 | 1 | 3.9 | 1.0 | -- | .02464 | 6.9 | single | cylinder | 8.0 | 8.0 | 8.0 | 9.5 | 6.9 | 0 |
| 17 | 121 | 4 | 08-27-92 | 1110 | 1 | 6.4 | 1.0 | -- | .02464 | 6.9 | single | cylinder | 8.0 | 8.0 | 8.0 | 8.7 | 7.4 | 0 |
| 17 | 122 | 5 | 01-25-90 | 0900 | 1 | 4.7 | 1.0 | -- | .02464 | 6.9 | single | cylinder | 8.0 | 8.0 | 8.0 | 10.0 | 5.7 | 0 |
| 17 | 123 | 5 | 08-27-92 | 1055 | 1 | 4.5 | 1.0 | -- | .02464 | 6.9 | single | cylinder | 8.0 | 8.0 | 8.0 | 10.2 | 6.6 | 0 |
| 18 | 124 | 4 | 04-13-74 | 1510 | 1 | 2.0 | 1.0 | -- | .01411 | 8.3 | single | square | 1.9 | 20.9 | 5.9 | 16.0 | 1.8 | 11 |
| 18 | 125 | 4 | 01-25-90 | 1730 | 1 | 2.5 | 1.0 | 45 | .01411 | 8.3 | single | square | 3.8 | 22.0 | 6.8 | 6.5 | 2.3 | 8 |
| 18 | 126 | 5 | 04-29-53 | 1650 | 2 | 2.8 | 2.0 | -- | .01411 | 8.3 | single | square | 2.2 | 21.2 | 7.3 | 5.3 | 5.0 | 14 |
| 18 | 127 | 5 | 12-17-59 | 1145 | 2 | 2.8 | 2.0 | -- | .01411 | 8.3 | single | square | 2.2 | 21.2 | 6.2 | 4.7 | 5.5 | 11 |
| 18 | 128 | 5 | 03-28-61 | 1120 | 2 | 2.7 | 2.0 | -- | .01411 | 8.3 | single | square | 2.1 | 21.1 | 2.1 | 11.6 | 6.8 | 0 |
| 18 | 129 | 5 | 09-16-71 | 1700 | 2 | 0.6 | 2.0 | 20 | .01411 | 8.3 | single | square | 2.4 | 21.3 | 2.4 | 2.4 | 5.7 | 0 |
| 18 | 130 | 5 | 12-06-71 | 1140 | 1 | 1.7 | 1.0 | -- | .01411 | 8.3 | single | square | 2.2 | 21.2 | 5.1 | 9.3 | 5.4 | 8 |
| 18 | 131 | 5 | 04-13-74 | 1510 | 1 | 4.4 | 1.0 | 60 | .01411 | 8.3 | single | square | 2.1 | 21.2 | 6.1 | 15.9 | 6.2 | 11 |
| 18 | 132 | 5 | 07-02-81 | 1110 | 2 | 2.8 | 2.0 | 56 | .01411 | 8.3 | single | square | 3.6 | 22.5 | 7.8 | 9.7 | 6.0 | 11 |
| 18 | 133 | 5 | 01-25-90 | 1730 | 1 | 3.8 | 1.0 | 33 | .01411 | 8.3 | single | square | 3.6 | 22.4 | 8.9 | 5.9 | 6.3 | 14 |
| 18 | 134 | 6 | 04-29-53 | 1650 | 2 | 1.6 | 2.0 | -- | .01411 | 8.3 | single | square | 2.2 | 21.3 | 2.2 | 3.6 | 5.0 | 0 |
| 18 | 135 | 6 | 12-17-59 | 1145 | 2 | 2.6 | 2.0 | -- | .01411 | 8.3 | single | square | 2.2 | 21.2 | 5.1 | 2.8 | 5.3 | 8 |
| 18 | 136 | 6 | 07-02-81 | 1110 | 2 | 1.7 | 2.0 | -- | .01411 | 8.3 | single | square | 2.2 | 21.2 | 8.6 | 7.0 | 6.7 | 18 |
| 18 | 137 | 6 | 01-25-90 | 1520 | 2 | 1.3 | 1.0 | 40 | .01411 | 8.3 | single | square | 2.3 | 21.3 | 6.3 | 3.6 | 5.1 | 11 |
| 18 | 138 | 7 | 04-29-53 | 1650 | 2 | 1.0 | 2.0 | -- | .01411 | 8.3 | single | square | 2.0 | 21.0 | 4.9 | 2.9 | 3.1 | 8 |
| 18 | 139 | 7 | 12-17-59 | 1145 | 2 | 1.0 | 2.0 | -- | .01411 | 8.3 | single | square | 2.0 | 21.0 | 4.9 | 3.0 | 6.4 | 8 |
| 18 | 140 | 7 | 03-28-61 | 1120 | 2 | 2.9 | 2.0 | -- | .01411 | 8.3 | single | square | 1.8 | 20.8 | 1.8 | 8.7 | 4.7 | 0 |
| 18 | 141 | 7 | 12-06-71 | 1140 | 1 | 1.7 | 1.0 | -- | .01411 | 8.3 | single | square | 2.0 | 21.0 | 7.0 | 7.8 | 6.7 | 14 |
| 18 | 142 | 7 | 04-13-74 | 1510 | 1 | 1.7 | 1.0 | -- | .01411 | 8.3 | single | square | 1.8 | 20.8 | 5.7 | 12.3 | 5.9 | 11 |
| 18 | 143 | 7 | 07-02-81 | 1110 | 2 | 1.5 | 2.0 | -- | .01411 | 8.3 | single | square | 2.0 | 21.2 | 2.0 | 5.1 | 3.7 | 0 |
| 18 | 144 | 7 | 01-25-90 | 1730 | 1 | 0.8 | 1.0 | 40 | .01411 | 8.3 | single | square | 2.1 | 21.1 | 6.1 | 3.3 | 3.6 | 11 |
| 19 | 145 | A | 12-27-42 | 1800 | 2 | 1.2 | 2.0 | -- | .00128 | 2.1 | group | cylinder | 3.0 | 20.0 | 3.0 | 4.5 | 3.5 | 0 |
| 19 | 146 | A | 04-01-47 | 2400 | 2 | 3.9 | 2.0 | -- | .00128 | 2.1 | group | cylinder | 3.0 | 20.0 | 6.0 | 4.3 | 3.1 | 11 |
| 19 | 147 | A | 04-11-47 | 1440 | 2 | 1.8 | 2.0 | -- | .00128 | 2.1 | group | cylinder | 3.0 | 20.0 | 6.0 | 3.6 | 2.6 | 14 |
| 19 | 148 | B | 12-27-42 | 1800 | 2 | 1.3 | 2.0 | -- | .00128 | 2.1 | group | cylinder | 3.0 | 20.0 | 3.0 | 4.7 | 7.6 | 0 |

**Table 3.** Pier-scour data collected at selected bridge sites in Mississippi--**Continued**

| Bridge site no. | Measurement no. | Pier ID | Date | Time (24-hour) | Loc. code | Measured pier scour | | | Bed material | | Pier geometry | | | | | Approach flow | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Depth (ft) | Acc. (ft) | Width (ft) | $D_{50}$ (ft) | $\sigma_g$ | Type | Shape | Width (ft) | Length (ft) | Normal width (ft) | Depth (ft) | Velocity (ft/s) | Skew (degrees) |
| 19 | 149 | B | 04-01-47 | 2400 | 2 | 3.5 | 2.0 | -- | 0.00128 | 2.1 | group | cylinder | 3.0 | 20.0 | 6.0 | 6.1 | 7.0 | 11 |
| 19 | 150 | B | 04-11-47 | 1440 | 2 | 2.8 | 2.0 | -- | .00128 | 2.1 | group | cylinder | 3.0 | 20.0 | 6.0 | 3.8 | 5.6 | 11 |
| 20 | 151 | 2 | 12-06-71 | 1650 | 2 | 3.0 | 2.0 | -- | .00128 | 2.1 | single | sharp | 4.6 | 20.1 | 4.6 | 20.0 | 10.4 | 0 |
| 20 | 152 | 3 | 12-06-71 | 1650 | 2 | 3.8 | 2.0 | -- | .00128 | 2.1 | single | sharp | 4.3 | 20.1 | 4.3 | 8.2 | 6.5 | 0 |
| 21 | 153 | 3 | 11-30-77 | 1200 | 2 | 4.5 | 3.0 | 125 | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 7.3 | 5.1 | 20 |
| 21 | 154 | 3 | 03-28-80 | 1330 | 1 | 6.3 | 3.0 | -- | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 2.7 | 2.1 | 0 |
| 21 | 155 | 3 | 12-04-82 | 1235 | 1 | 2.5 | 3.0 | -- | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 6.5 | 7.3 | 18 |
| 21 | 156 | 3 | 05-19-89 | 1210 | 1 | 2.5 | 2.0 | 100 | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 3.0 | 5.7 | 8 |
| 21 | 157 | 3 | 01-28-94 | 0815 | 1 | 2.7 | 3.0 | -- | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 3.3 | 5.1 | 0 |
| 21 | 158 | 4 | 11-30-77 | 1200 | 2 | 6.9 | 3.0 | -- | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 15.1 | 5.9 | 16 |
| 21 | 159 | 4 | 08-29-78 | 1735 | 2 | 5.2 | 3.0 | 100 | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 9.3 | 9.4 | 11 |
| 21 | 160 | 4 | 03-28-80 | 1330 | 1 | 10.6 | 3.0 | -- | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 7.4 | 6.7 | 35 |
| 21 | 161 | 4 | 12-04-82 | 1235 | 2 | 5.8 | 3.0 | -- | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 6.3 | 6.3 | 0 |
| 21 | 162 | 4 | 04-06-83 | 1245 | 2 | 5.1 | 3.0 | -- | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 4.8 | 7.2 | 11 |
| 21 | 163 | 4 | 10-23-84 | 1040 | 2 | 5.7 | 3.0 | -- | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 2.3 | 3.8 | 8 |
| 21 | 164 | 4 | 05-19-89 | 1210 | 1 | 5.0 | 2.0 | 105 | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 5.5 | 4.9 | 8 |
| 21 | 165 | 4 | 01-25-90 | 1715 | 2 | 8.8 | 2.0 | 112 | .00118 | 1.8 | single | cylinder | 23.0 | 25.0 | 23.0 | 8.8 | 3.4 | 0 |
| 21 | 166 | 5 | 03-28-80 | 1330 | 1 | 12.3 | 3.0 | 130 | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 13.0 | 6.1 | 28 |
| 21 | 167 | 5 | 12-04-82 | 1235 | 1 | 4.2 | 3.0 | -- | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 16.8 | 7.7 | 0 |
| 21 | 168 | 5 | 02-01-83 | 1500 | 2 | 4.5 | 3.0 | 125 | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 12.9 | 7.2 | 0 |
| 21 | 169 | 5 | 04-06-83 | 1245 | 2 | 10.0 | 3.0 | 130 | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 11.0 | 6.5 | 0 |
| 21 | 170 | 5 | 05-19-89 | 1335 | 2 | 4.8 | 2.0 | 180 | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 9.2 | 7.1 | 18 |
| 21 | 171 | 5 | 01-25-90 | 1750 | 2 | 5.3 | 2.0 | 172 | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 14.6 | 6.9 | 0 |
| 21 | 172 | 5 | 02-16-90 | 1450 | 1 | 6.4 | 3.0 | 58 | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 7.6 | 7.5 | 18 |
| 21 | 173 | 5 | 11-15-93 | 1640 | 1 | 5.5 | 3.0 | 155 | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 8.0 | 7.5 | 20 |
| 21 | 174 | 5 | 01-28-94 | 0815 | 1 | 6.2 | 3.0 | -- | .00118 | 1.8 | single | cylinder | 15.0 | 15.0 | 15.0 | 16.3 | 7.6 | 26 |
| 22 | 175 | 43 | 03-03-48 | 0950 | 1 | 4.3 | 2.0 | -- | .00098 | -- | single | square | 4.6 | 23.9 | 16.3 | 12.7 | 4.1 | 31 |
| 22 | 176 | 43 | 01-06-50 | 1130 | 1 | 5.5 | 2.0 | -- | .00098 | -- | single | square | 2.8 | 22.3 | 16.0 | 13.3 | 8.7 | 39 |
| 22 | 177 | 43 | 03-28-61 | 1545 | 2 | 3.4 | 2.0 | -- | .00098 | -- | single | square | 2.8 | 22.3 | 12.9 | 14.9 | 10.1 | 28 |
| 22 | 178 | 43 | 08-04-75 | 1840 | 2 | 4.4 | 2.0 | -- | .00098 | -- | single | square | 2.8 | 22.3 | 14.2 | 6.4 | 4.5 | 32 |

**Table 3.** Pier-scour data collected at selected bridge sites in Mississippi--**Continued**

| Bridge site no. | Measurement no. | Pier ID | Date | Time (24-hour) | Loc. code | Measured pier scour: Depth (ft) | Measured pier scour: Acc. (ft) | Measured pier scour: Width (ft) | Bed material: $D_{50}$ (ft) | Bed material: $\sigma_g$ | Pier geometry: Type | Pier geometry: Shape | Pier geometry: Width (ft) | Pier geometry: Length (ft) | Pier geometry: Normal width (ft) | Approach flow: Depth (ft) | Approach flow: Velocity (ft/s) | Approach flow: Skew (degrees) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22 | 179 | 43 | 04-21-77 | 1410 | 2 | 20.4 | 2.0 | 90 | 0.00098 | -- | single | square | 4.2 | 23.7 | 14.2 | 18.6 | 9.6 | 26 |
| 22 | 180 | 43 | 04-22-79 | 1730 | 2 | 13.8 | 2.0 | -- | .00098 | -- | single | square | 5.8 | 25.2 | 13.3 | 28.0 | 10.3 | 18 |
| 22 | 181 | 43 | 04-06-83 | 1510 | 2 | 4.1 | 2.0 | -- | .00098 | -- | single | square | 5.5 | 24.9 | 19.4 | 19.7 | 5.4 | 37 |
| 22 | 182 | 43 | 03-31-88 | 1840 | 1 | 6.1 | 2.0 | -- | .00098 | -- | single | square | 4.5 | 23.9 | 16.5 | 12.9 | 7.5 | 32 |
| 22 | 183 | 43 | 01-24-90 | 1700 | 1 | 4.0 | 2.0 | -- | .00098 | -- | single | square | 4.6 | 24.3 | 16.8 | 24.0 | 8.9 | 32 |
| 22 | 184 | 44 | 03-03-48 | 0950 | 2 | 7.4 | 2.0 | -- | .00098 | -- | single | square | 2.8 | 22.3 | 7.0 | 10.6 | 4.0 | 11 |
| 22 | 185 | 44 | 05-18-53 | 0745 | 1 | 11.3 | 2.0 | -- | .00098 | -- | single | square | 2.8 | 22.3 | 18.0 | 6.9 | 5.4 | 46 |
| 22 | 186 | 44 | 03-28-61 | 1545 | 2 | 6.9 | 2.0 | -- | .00098 | -- | single | square | 2.8 | 22.3 | 10.3 | 15.1 | 6.9 | 20 |
| 22 | 187 | 44 | 04-21-77 | 1410 | 2 | 6.0 | 2.0 | -- | .00098 | -- | single | square | 4.5 | 24.2 | 11.0 | 20.4 | 8.1 | 16 |
| 22 | 188 | 44 | 04-22-79 | 1730 | 2 | 6.7 | 2.0 | -- | .00098 | -- | single | square | 5.4 | 24.9 | 12.0 | 25.9 | 7.4 | 16 |
| 22 | 189 | 44 | 04-06-83 | 1510 | 2 | 4.1 | 2.0 | -- | .00098 | -- | single | square | 5.4 | 24.7 | 20.3 | 19.0 | 6.4 | 41 |
| 22 | 190 | 44 | 03-31-88 | 1840 | 1 | 2.9 | 2.0 | -- | .00098 | -- | single | square | 2.8 | 22.3 | 14.2 | 7.1 | 4.5 | 32 |

With inclusion of the selected historical discharge measurements, the recurrence intervals of the measured discharges ranged from less than 2 to about 500 years (table 2). Recurrence intervals of the measured discharges were determined using procedures and information described by Landers and Wilson (1991) and Wilson and Landers (1991).

The majority of the pier-scour data presented in this report have been entered in the National Bridge Scour Data Management System (BSDMS). The BSDMS is being developed by the USGS in cooperation with the FHWA to support preparation, compilation, and analysis of bridge- scour measurement data, and the primary functions of the BSDMS are data archival and retrieval (Landers, 1992).

Pier-scour data were collected during high flows at selected bridge sites in Mississippi representing various hydraulic, bed-material and pier-geometry characteristics (table 3). Measured pier-scour depths ($Y_s$) ranged from 0.6 to 20.4 ft and are plotted in relation to drainage area in figure 2. No defined relation between measured pier-scour depth and drainage area was determined. Scour-hole top width, where determined, ranged from 8 to 180 ft. Approach-flow depth ($Y_1$) ranged from 2.3 to 36.6 ft, approach-flow velocity ($V_1$) ranged from 1.3 to 10.4 ft/s, and approach-flow skew ranged from 0 to 46 degrees. Median bed-material size ($D_{50}$) ranged from 0.00092 to 0.02464 ft, and the geometric standard deviation of the bed-material sizes or the gradation coefficient

$$\sigma_g = \sqrt{\frac{D_{84}}{D_{16}}} \qquad (1)$$

ranged from 1.3 to 8.3. In this equation, $D_{84}$ is bed-material size where 84 percent is finer, and $D_{16}$ is bed-material size where 16 percent is finer. If $\sigma_g$ is equal to 1, the material is considered uniform in size, and as $\sigma_g$ increases, the material is less uniform.

## PIER GEOMETRY

The pier geometry listed in table 3 was determined from field observations and MDOT bridge plans. The pier type was classified as either a single or a group. A single refers to one pier or column supporting the entire bridge width; whereas, a group refers to spaced columns or piles. The pier shape refers to the upstream part of the pier and was classified as either cylinder, round, square, or sharp. The pier width ($a$) and the pier length ($L$) are depth-weighted averages for each respective measurement. The normal pier width ($a'$) is the pier width adjusted for skew. If skew is zero, then $a$ is equal to $a'$; otherwise, $a'$ will be larger than $a$, depending on the degree of skew. For the approach flow skews ranging from 0 to 46 degrees, measured $a$ and $a'$ ranged from 1.3 to 23 ft and 1.8 to 23 ft, respectively (table 3).

Fotherby and Jones (1993) and Jones and others (1992) studied the influence of exposed footings on pier-scour depths. None of the existing pier-scour equations have provisions to account for nonuniform pier configurations. Jones and others (1992) evaluated three techniques for characterizing the effective dimensions for a pier/footing combination when both are exposed to the approach flow. Jones and others (1992) found the depth-weighted average pier width technique, as used in this report, to be as accurate and easier to use than the dominant pier/footing component technique. The dominant pier/footing component technique consists of making two computations with appropriate flow parameters and selecting the larger value as recommended in HEC-18 by Richardson and others (1993).

Some of the measured pier-scour depths were affected by the location of the footing, which consisted of one of four types (fig. 3). The location of the footing in relation to the approach flow was considered in determining the depth-weighted average of the pier width and length. The depth-weighted average pier width shown in figures 3a, 3b, and 3c is that of

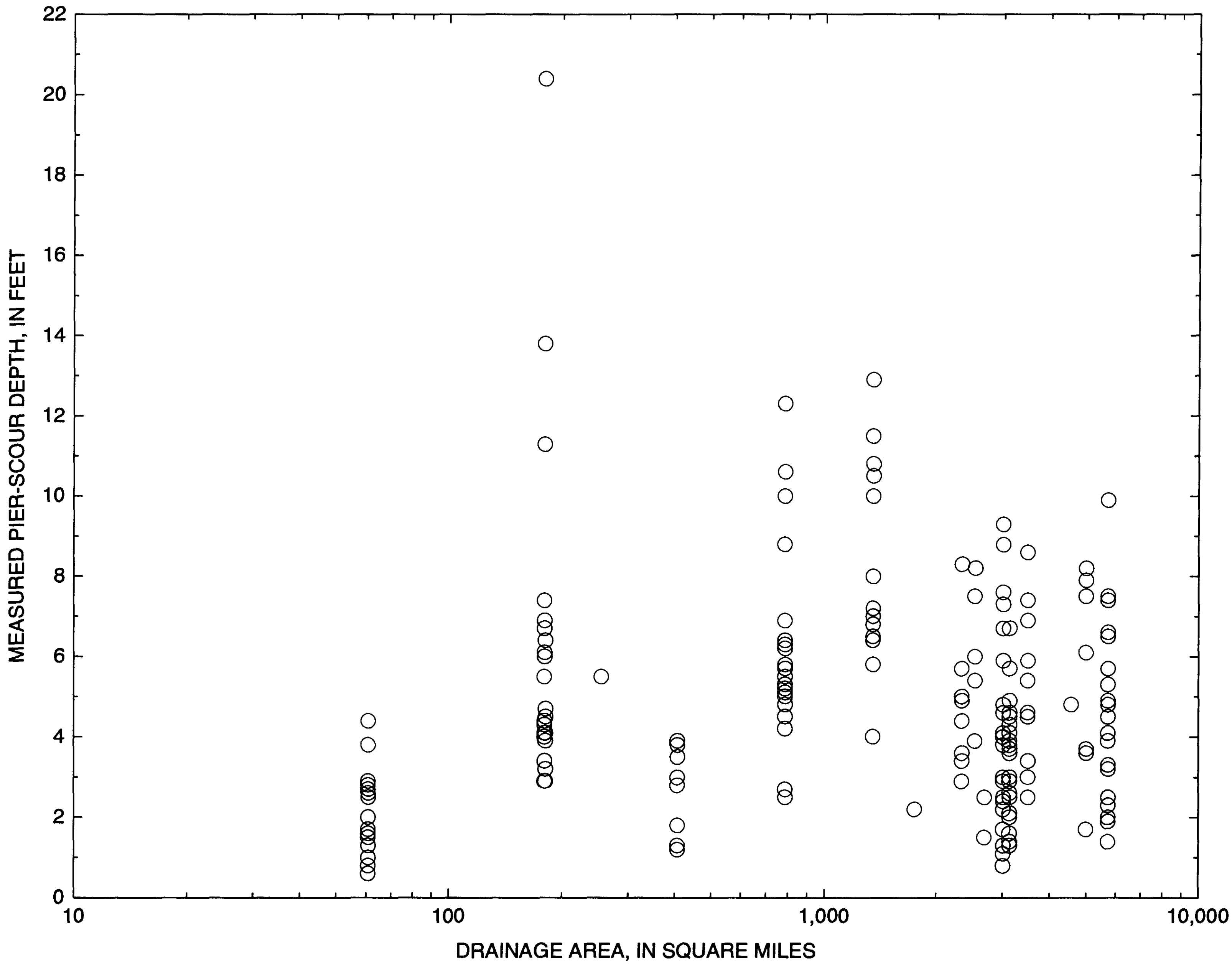


**Figure 2.** Relation between measured pier-scour depth and drainage area for selected bridge sites in Mississippi.

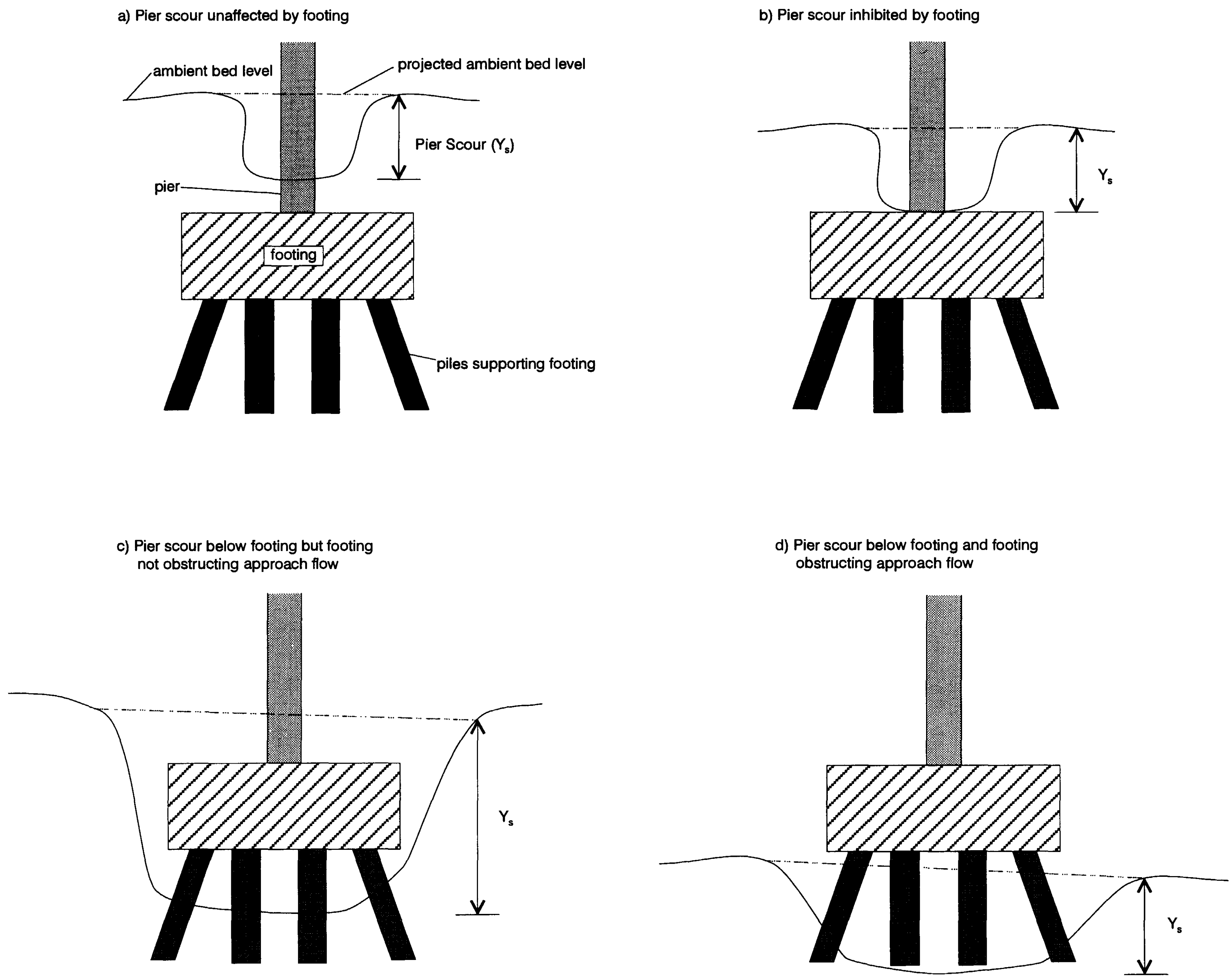


**Figure 3**. Four typical locations of pier footing in relation to approach flow.

the pier width only because the footing is not obstructing the approach flow depth above ambient bed level. However, the pier width shown in figure 3d is a depth-weighted average of the pier, footing, and piles, because they all obstruct the approach flow. At some sites, the footing was undercut and piles were exposed to the approach flow (fig. 3d). If the piles were not exposed by more than the depth of the footing, the footing width was held constant from the bottom of the footing to ambient bed level. If the piles were exposed by more than the depth of the footing, and debris was insignificant, then the widths of the pier, footing, and piles were used to determine a depth-weighted average of pier width.

The areal extent of the footing can be a significant factor in pier-scour depth computations. Pier-scour equations do not currently include an adjustment factor for footing extensions in front of the pier and for footing extensions on the side of the pier. Figure 3b and 3c are examples where the footing is inhibiting additional pier scour if the areal extent of the footing is sufficient to turn the downward vortices upward from the erodible channel bed. However, in figure 3d, the footing could be either inhibiting or increasing scour depths depending on the areal extent of the footing in proportion to the pier and the distance of the footing above ambient bed level. If pier-scour depth is being inhibited for the examples shown in figures 3b, 3c, and 3d, scour at the downstream side of the footing could be increased; this was observed to be the case at several sites during this study. Data collected at sites 8,9,12, and 13, where the footings on some of the bridge piers are above ambient bed level and obstruct the approach flow, could be included in research on the influence of exposed footings on pier scour.

## PIER-SCOUR DATA ANALYSIS

Jones (1984) compared many pier-scour equations by plotting measured pier-scour depth divided by pier width ($Y_s/a$) with approach depth divided by pier width ($Y_1/a$) for various Froude numbers. However, in this report, pier-scour depth ($Y_s$) was divided by normal pier width ($a'$). Only 12 of the 190 measurements (6 percent) are plotted above $Y_s/a' = 1.1$ (fig. 4). The envelope-curve equation developed for these data (fig. 4) is:

$$\frac{Y_s}{a'} = 0.9\left(\frac{Y_1}{a'}\right)^{0.4} \qquad (2)$$

where

$Y_s$ is pier-scour depth, in feet;
$a'$ is normal pier width, in feet; and
$Y_1$ is approach flow depth, in feet.

Measurement 179 at site 22 (table 3) is the only measurement that is plotted significantly above the envelope curve (fig. 4). Measurement 179 is affected by a jetty and stream bank deflecting flow toward the pier and possibly debris, which was not noted during the measurement. Using techniques described by Lagasse and others (1991) for estimating scour off the downstream end of the jetty, the jetty could have caused about 9 ft of scour off its downstream end, suggesting some of the measured pier-scour could have been caused by the jetty. Equation 2 predicts 14.2 ft of pier scour, which is 6.2 ft less than the measured pier scour of 20.4 ft, suggesting about 6 ft of scour not caused by the pier.

Measured pier-scour depths have been shown not to exceed a certain multiple of the pier width. F.M. Chang noted that there were no pier-scour depths greater than 2.3 times the pier width for all the pier-scour data he studied (Richardson and others, 1993). Melville and Sutherland (1988) reported from laboratory data there were no pier-scour depths greater than 2.4 times the pier width for cylindrical piers.

All of the Mississippi pier-scour depths were within 2.3 times the normal pier width, which agreed with previous research (fig. 5).

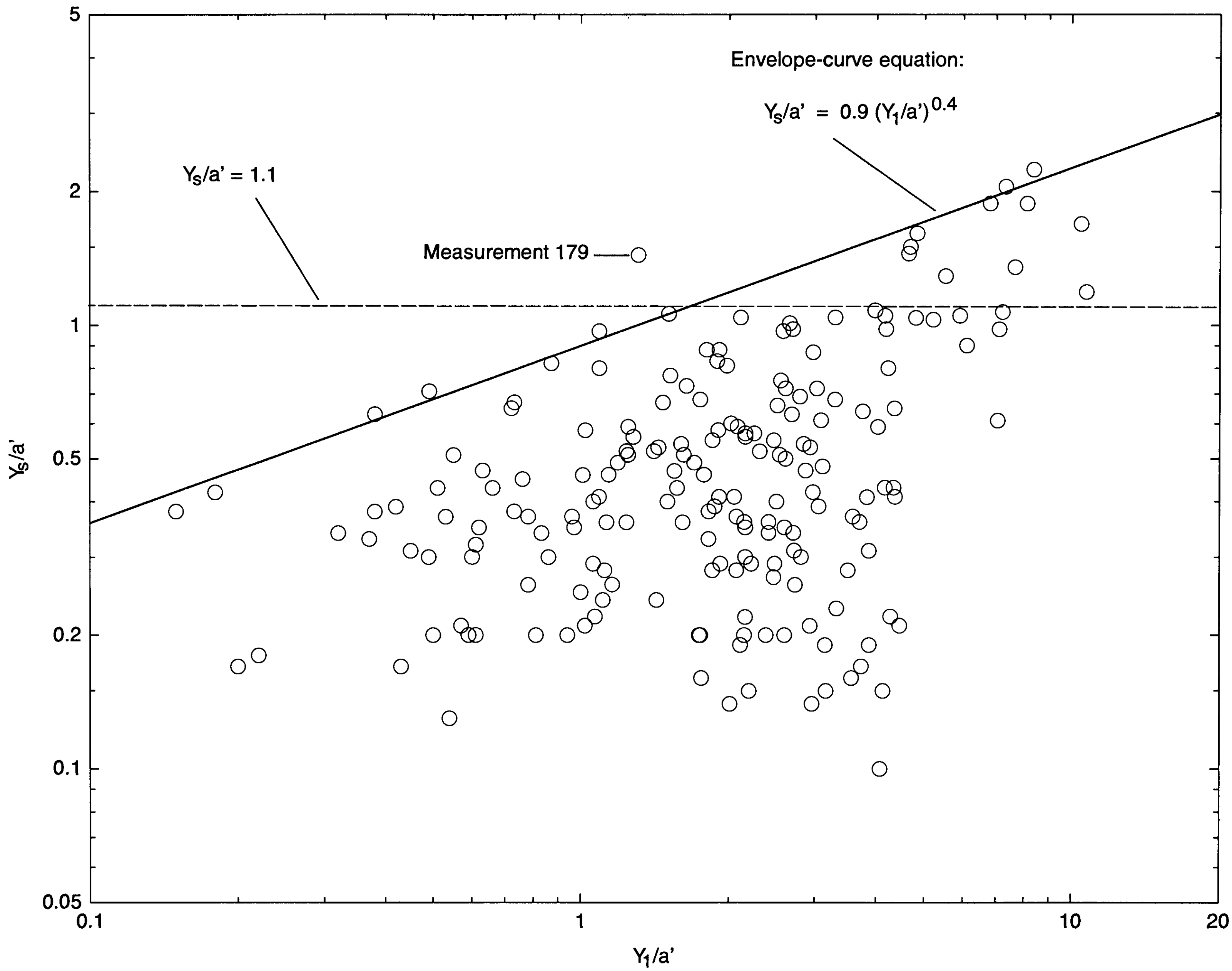


**Figure 4.** Relation between measured pier-scour depth divided by normal pier width ($Y_S/a'$) and measured approach-flow depth divided by normal pier width ($Y_1/a'$) for selected bridge sites in Mississippi.

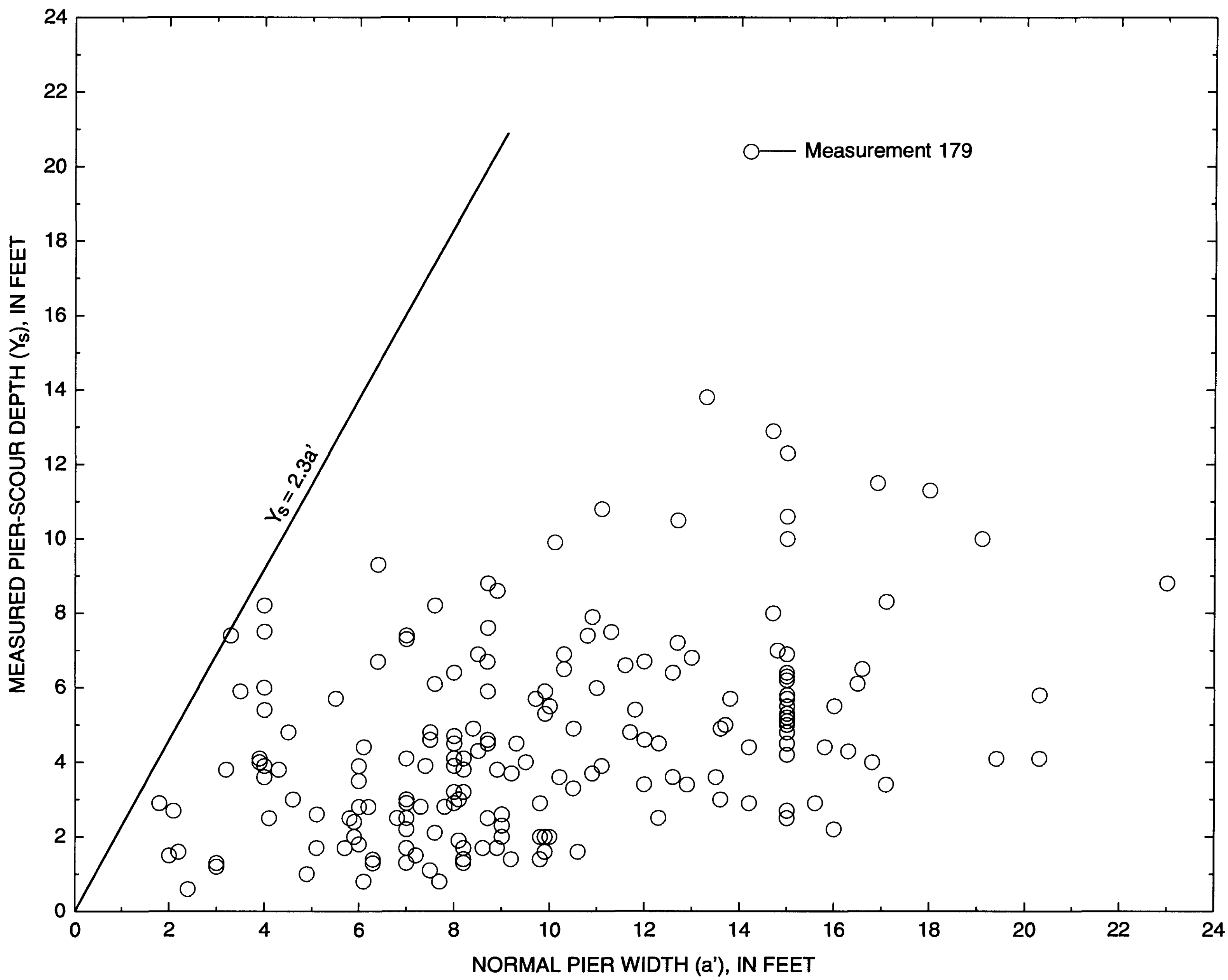


**Figure 5.** Relation between measured pier-scour depth ($Y_s$) and normal pier width (a') for selected bridge sites in Mississippi.

Measured pier-scour depths were as much as 2.24 times a normal pier width of 3.3 ft. However, for normal pier widths greater than about 4 ft, measured pier-scour depths were significantly less than 2.3 times the normal pier width (fig. 5).

The measured pier-scour hole top width generally increased as pier-scour depth increased (fig. 6). The range of top widths for a respective pier-scour depth possibly were distorted due to the variations in flow conditions, pier geometry, bed material, and accuracy of the measurements. For example, the pier-scour hole top width ranged from about 20 to 180 ft for a pier-scour depth of 5 ft (fig. 6).

## Effect of Debris Piles

During a few measurements, debris piles on bridge piers were present where the debris significantly obstructed more of the approach flow than did the pier. The debris accumulating on a pier can affect the location and magnitude of the maximum pier-scour depth caused by the combination of the pier and the debris pile. Where the debris pile was significant on the upstream side of the pier, the maximum measured pier-scour depth usually was on the downstream side of the pier. In most cases, if debris was present, it was considered insignificant because the debris at the water surface consisted of only a few logs, which did not significantly increase the pier obstruction of the approach flow. Some of the fathometer records indicated the possible presence of submerged debris, which might have had an effect on some of the measured pier-scour depths.

The largest debris pile observed in this study was for measurement 165 at site 21, pier 4. At the time of the measurement, January 25, 1990, the size of the debris pile could not be easily determined. However, a low-water survey on September 18, 1990, documented the debris pile to be about 11 ft high, 10 ft wide at the top, and 40 ft wide at the bottom. If the debris did not slip downward, the debris pile projected about 5 ft above the ambient bed level during measurement 165. The maximum scour-hole depth of 9.4 ft was surveyed on September 18, 1990, at the upstream side of the debris pile, which was about 25 ft upstream of the upstream side of bridge pier. The surveyed scour-hole depth of 9.4 ft agreed reasonably well with the pier-scour depth of 8.8 ft obtained at the downstream side of the bridge during measurement 165 (table 3). The pier width of 23 ft (table 3) includes the debris, which is about 8 ft wider than or 1.5 times as wide as the bridge-pier width of 15 ft.

## Effect of Heterogeneous Bed Material

At several sites, measured pier-scour depths possibly were affected by heterogeneous bed material, primarily where a clay stratum was overlain by sand and(or) gravel. If the material was uniform with depth, then the bed sample taken during low-flow conditions was assumed to be representative of the bed material during high-flow conditions. If the material contained a range of fine to coarse material, then the coarse material would most likely be overlain with fine material during low-flow conditions. Therefore, the low-flow bed sample would not necessarily be representative of high-flow conditions.

Large-scale laboratory studies are being conducted by Albert Molinas at Colorado State University (CSU) for FHWA to test the effects of gradation and cohesion of streambed material on scour. Preliminary findings indicate the gradation of the material has a significant effect on the scour depth. If there is even a small amount of gravel mixed with sand, the gravel is deposited in the scour hole at the base of the pier, and the gravel possibly provides an armor layer during flow conditions below the initiation of motion of the gravel (A. Molinas, CSU, and J.S. Jones, FHWA, oral commun., 1995). For the Mississippi data, the range of measured pier-scour depths for a respective $D_{50}$ generally decreased as $D_{50}$ increased and as $\sigma_g$ increased.

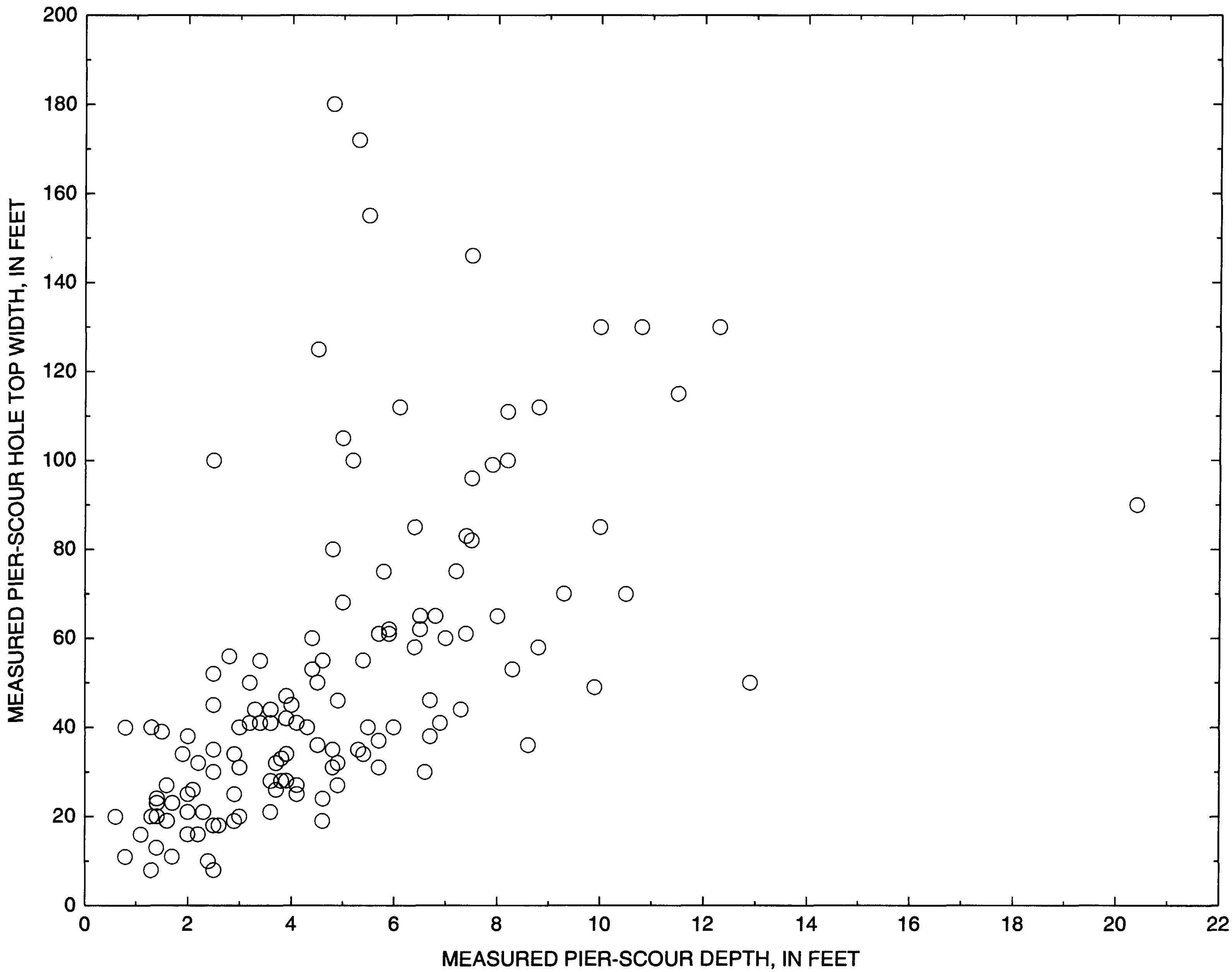


**Figure 6.** Relation between measured pier-scour hole top width and measured pier-scour depth for selected bridge sites in Mississippi.

Osman and Thorne (1988) presented a method for calculating the rate and amount of erosion of cohesive material based on laboratory work by the U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, Mississippi. Osman and Thorne noted that increasing the clay content in the soil or decreasing the sodium concentration in the soil, increases the resistance of the soil to erosion. They also noted decreasing the clay content or the sodium concentration in the eroding water, decreases the resistance of the soil to erosion.

Kamphuis(1990) determined that the erosion of consolidated cohesive soils was dependent on the transport properties of sparse amounts of granular material overlying the cohesive soil or transported by the eroding stream. Kamphuis indicated that sand in the eroding stream decreases the critical shear stress required for erosion of the clay, increases erosion volume and erosion rate of the clay, and determines where erosion occurs in the clay. Erosion of the clay typically occurs at protrusions and not at depressions. Kamphuis suggested that bridge design should be based on the sediment transport characteristics of the noncohesive granular material for a stream where sand and(or) gravel overlay a cohesive clay in a discontinuous layer. The gradation of the bed-load material is a factor in the grinding or blasting away of the underlying cohesive material or possibly in the protection of the cohesive material, depending on whether the given flow produces velocities sufficient to initiate motion of the granular material.

Where MDOT soil reports were available, the cohesion and friction angles were approximated for the clays at sites where the clay stratum is thought to inhibit scour. Using the MDOT borings where the clay was overlain by sand and(or) gravel, the top of the clay stratum was approximated in order to determine the net scour through the clay. Pier-scour measurements, which are possibly affected by the presence of a consolidated cohesive material, are listed in table 4. The net pier-scour depth through the clay ($Y_{scl}$) is a rough approximation where sand and(or) gravel overlay a clay stratum and, therefore, only represent part of the entire pier-scour depth. The pier-scour depths for measurements 54 to 57 and 68 to 71 for sites 8 and 9 are greater than expected because the lateral movement of the Pearl River toward these piers has caused the formation of secondary channels, which have influenced scour depth.

The relation between $Y_{scl}/a'$ and approximate shear strength of the clay is shown in figure 7. With the exception of measurement 79 at site 10, pier-scour depths generally decreased as shear strength increased. It is a possibility that the clay may have been removed and replaced with more easily erodible material during construction at site 10, resulting in an unusually large pier-scour depth. Pier-scour measurements at all of the sites listed in table 4 likely are affected by some disturbance of the clays when the pier foundations were installed.

Figure 7 could be used graphically for comparison with predicted pier-scour depths for sites where the shear strength of a clay is thought to be inhibiting scour. A line through the highest points, with the exception of measurement 79 at site 10, possibly could be used as a guide for determining the largest amount of scour that could be expected for a given shear strength of a consolidated cohesive bed material at a site. Perhaps as more data become available, an envelope-curve equation could be developed.

## Determination of Live-bed or Clear-water Scour

Scour processes can occur under live-bed or clear-water conditions. Live-bed scour occurs if the flow upstream of a bridge transports significant amounts of bed material. Clear-water scour occurs if the flow upstream

**Table 4.** Selected pier-scour measurements possibly affected by consolidated cohesive material in Mississippi.
[ft, feet; lb/ft$^2$, pounds per square foot]

| Site no. | Meas no. | Pier ID | Pier scour (ft) | Pier scour in clay (ft) | Cohesion (lb/ft$^2$) | Friction angle (degrees) | Shear Strength (lb/ft$^2$) |
|---|---|---|---|---|---|---|---|
| 2 | 2 | A | 8.2 | 2.2[a] | 1,750 | 22 | 2,490 |
| 2 | 3 | A | 6.0 | 0.3[a] | 1,750 | 22 | 2,220 |
| 2 | 4 | A | 7.5 | 1.8[a] | 1,750 | 22 | 2,570 |
| 3 | 8 | 1 | 2.4 | 0[a] | 2,000 | 20 | 2,580 |
| 3 | 9 | 1 | 2.5 | 0[a] | 2,000 | 20 | 2,590 |
| 3 | 10 | 1 | 1.3 | 0[a] | 2,000 | 20 | 2,620 |
| 3 | 11 | 2 | 5.9 | 0[a] | 2,000 | 20 | 2,830 |
| 8 | 54 | 12L | 2.0 | 2.0 | 240 | 27 | 540 |
| 8 | 55 | 12L | 2.5 | 2.5 | 240 | 27 | 770 |
| 8 | 56 | 13L | 6.7 | 6.7 | 240 | 27 | 660 |
| 8 | 57 | 13L | 4.9 | 4.9 | 240 | 27 | 750 |
| 9 | 68 | 12R | 4.5 | 4.5 | 240 | 27 | 580 |
| 9 | 69 | 12R | 4.3 | 4.3 | 240 | 27 | 680 |
| 9 | 70 | 13R | 4.6 | 4.6 | 240 | 27 | 640 |
| 9 | 71 | 13R | 3.8 | 3.8 | 240 | 27 | 700 |
| 10 | 79 | 4 | 4.8 | 4.8 | 4,000 | 0 | 4,000 |
| 15 | 108 | 4R | 4.4 | 0.8[a] | 4,900 | 0 | 4,900 |
| 15 | 109 | 4R | 3.4 | 0[a] | 4,900 | 0 | 4,900 |
| 15 | 110 | 5R | 5.7 | 3.8[a] | 4,900 | 0 | 4,900 |
| 15 | 111 | 5R | 5.0 | 3.8[a] | 4,900 | 0 | 4,900 |
| 16 | 112 | 4L | 8.3 | 4.5[a] | 4,900 | 0 | 4,900 |
| 16 | 113 | 4L | 2.9 | 2.2[a] | 4,900 | 0 | 4,900 |
| 16 | 114 | 5L | 4.9 | 4.8[a] | 4,900 | 0 | 4,900 |
| 16 | 115 | 5L | 3.6 | 0.3[a] | 4,900 | 0 | 4,900 |
| 18 | 124 | 4 | 2.0 | 0[a] | 1,500 | 16 | 1,790 |
| 18 | 125 | 4 | 2.5 | 0[a] | 1,500 | 16 | 1,620 |
| 18 | 131 | 5 | 4.4 | 0[a] | 1,500 | 16 | 1,780 |
| 18 | 132 | 5 | 2.8 | 0[a] | 1,500 | 16 | 1,670 |
| 18 | 133 | 5 | 3.8 | 0[a] | 1,500 | 16 | 1,610 |

[a] Approximation based on limited data.

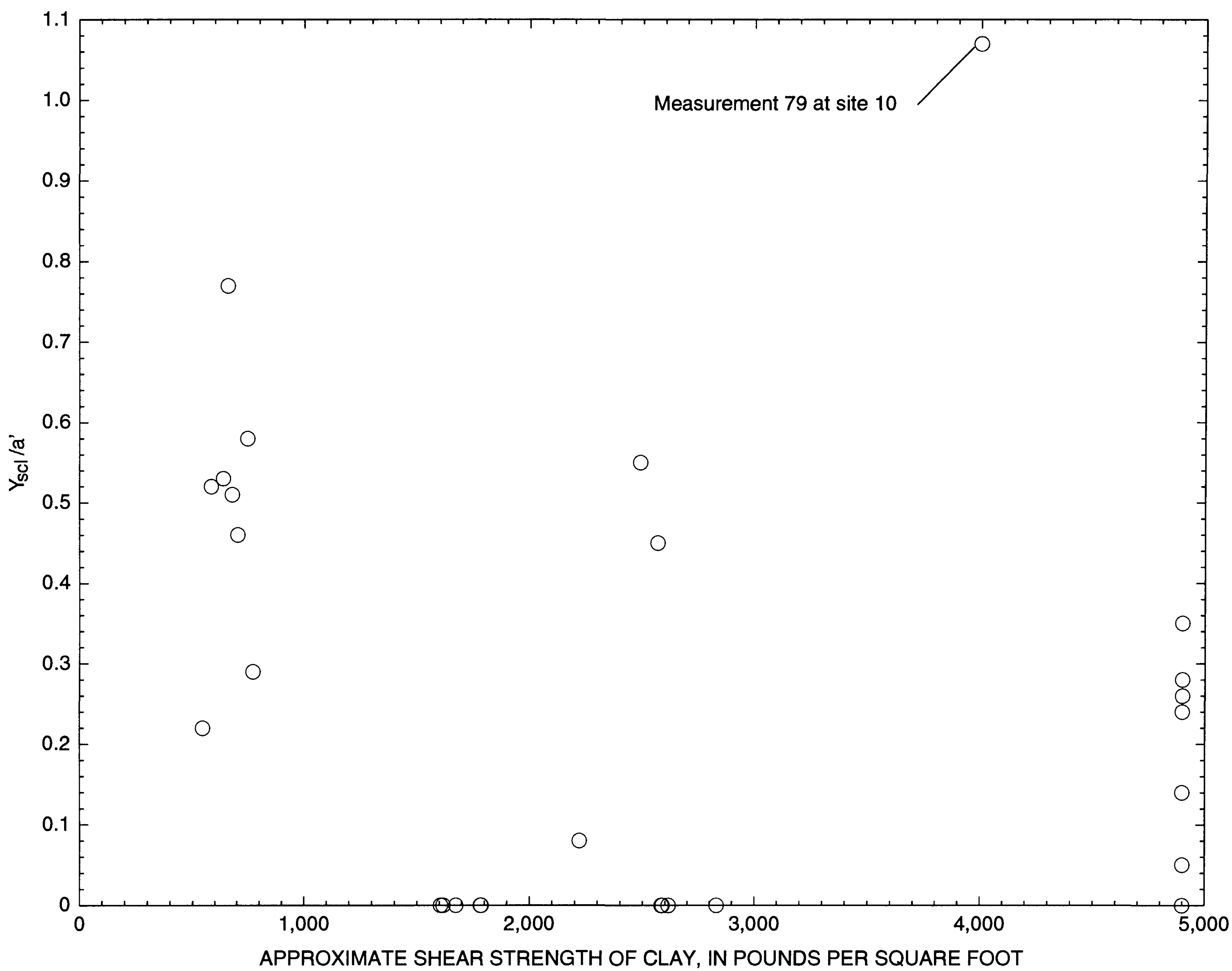


**Figure 7.** Relation between net pier-scour depth through clay divided by normal pier width ($Y_{scl}/a'$) and approximate shear strength of clay for selected bridge sites in Mississippi.

of the bridge does not transport significant amounts of bed material. It is important to determine live-bed or clear-water scour, because the rate at which the scour develops with time and the relation between scour depth and approach flow velocity depend on which condition dominates. Live-bed scour develops rapidly and then fluctuates with time around an equilibrium scour depth because of the presence of bed dunes. The maximum live-bed scour depth may be as much as 30 percent greater than the equilibrium live-bed scour depth when large bed dunes are present. Clear-water scour develops more slowly than live-bed scour and may not reach its maximum until after several floods. Maximum clear-water scour depth is about 10 percent greater than the equilibrium scour depth for live-bed scour (Richardson and others, 1993).

The critical velocity ($V_c$) was calculated and compared with the measured velocity ($V_1$) of the flow approaching the bridge piers to determine whether the measured pier-scour depth was live-bed or clear-water scour. If $V_1/V_c$ was greater than 1.0, then live-bed scour existed. If $V_1/V_c$ was less than 1.0, then clear-water scour existed. An equation developed by Neill (1968) and described in HEC-18 by Richardson and others (1993) was used to determine $V_c$. Neill's equation with the specific gravity of the bed material equal to 2.65 is as follows:

$$V_c = 11.52 Y_1^{1/6} D_{50}^{1/3} \qquad (3)$$

where

$V_c$ is critical velocity which will transport bed materials of the median bed-material size and smaller, in feet per second;
$Y_1$ is depth of approach flow, in feet; and
$D_{50}$ is median bed-material size.

The poor relation between $Y_s/a'$ and $V_1/V_c$ (fig. 8) suggests the measured pier-scour depths are not simply a function of the measured approach velocity and bed-material size. Geometry of scoured channels is rarely in equilibrium with the concurrent hydraulic and sediment transport characteristics (Landers and others, 1994). Using Neill's equation, some of the measured pier-scour depths were indicated as clear-water scour, but most were indicated as live-bed scour. For some sites, where the $D_{50}$ was determined and Neill's equation indicated clear-water scour, the $D_{50}$ used in Neill's equation was perhaps not representative of the entire bed material at the bridge site, and therefore, the measurement could have actually been live-bed scour. Landers and others (1994), in their preliminary analyses of the BSDMS pier-scour data, indicated a distinct upper limit for pier-scour depth as a function of velocity and bed-material size using Neill's equation. They suggested a possible envelope curve generally would flatten for $V_1/V_c$ greater than 1.0, indicating velocity is less significant to pier-scour depths for live-bed scour. However, this is not readily apparent for the Mississippi data (fig. 8).

## COMPARISON OF COMPUTED AND MEASURED PIER-SCOUR DEPTHS

Many pier-scour prediction equations have been published; however, only the equation currently (1994) recommended by FHWA in HEC-18 (Richardson and others, 1993) was selected for comparison with the measured Mississippi pier-scour data. The HEC-18 equation in terms of $Y_s/a$ is:

$$\frac{Y_s}{a} = 2.0 K_1 K_2 K_3 \left(\frac{Y_1}{a}\right)^{0.35} (Fr_1)^{0.43} \qquad (4)$$

where

$Y_s$ is pier-scour depth, in feet;
$a$ is pier width, in feet;
$K_1$ is correction factor for pier-nose shape from table 5;

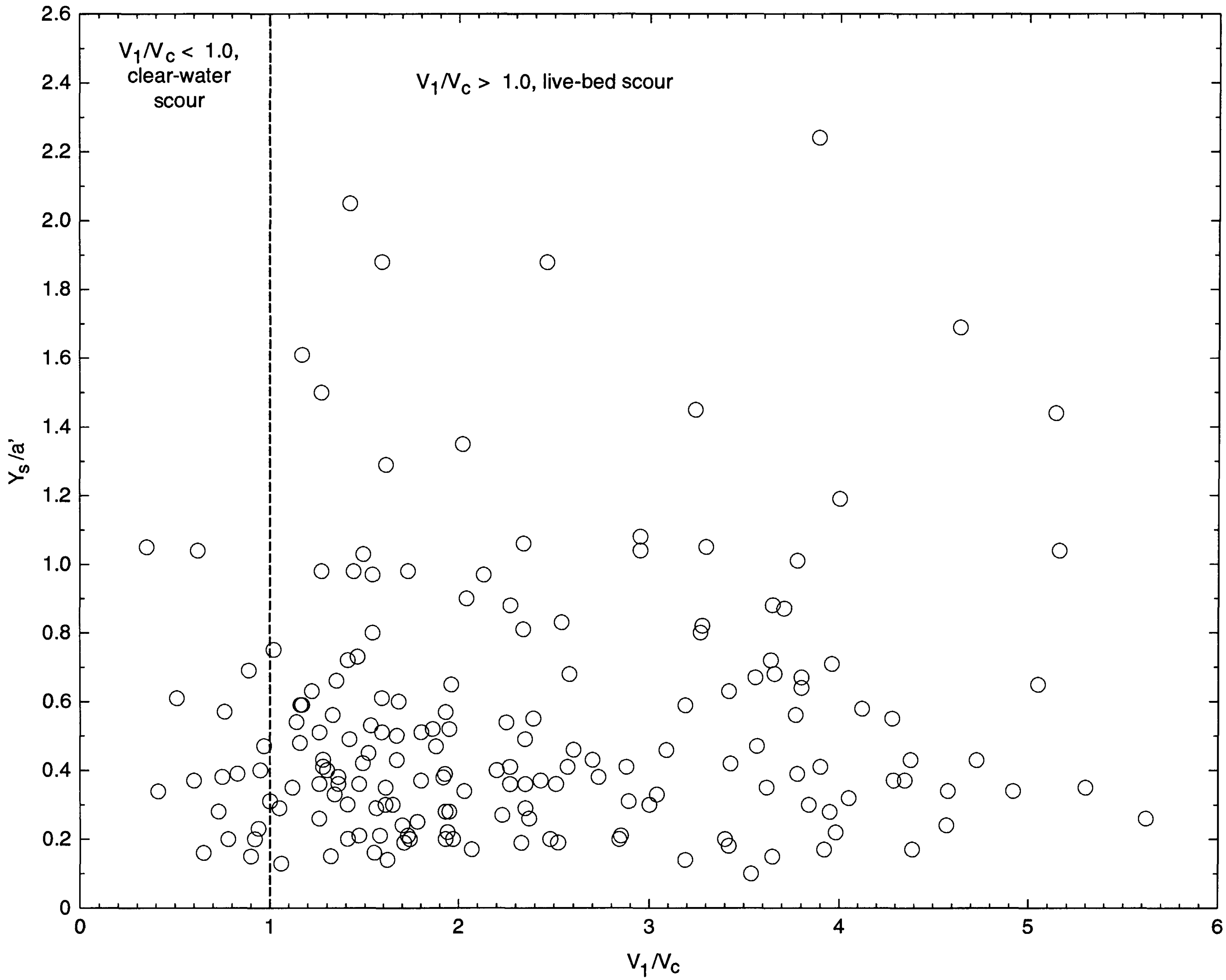


**Figure 8.** Relation between measured pier-scour depth divided by normal pier width ($Y_s/a'$) and approach velocity divided by critical velocity ($V_1/V_c$) for selected bridge sites in Mississippi.

$K_2$ is correction factor for approach-flow angle from table 6;
$K_3$ is correction factor for bed condition from table 7;
$Y_1$ is approach-flow depth directly upstream of pier, in feet;
$Fr_1$ is Froude number as defined as $V_1/(gY_1)^{0.5}$: where $V_1$ is mean velocity of the approach flow upstream of the pier, in feet per second; $g$ is the acceleration of gravity, in feet per second squared; and $Y_1$ is approach flow depth directly upstream of pier, in feet.

**Table 5.** Pier-shape correction factor ($K_1$) for the HEC-18 equation (from Richardson and others, 1993)

| Shape of pier nose | $K_1$ |
|---|---|
| Square nose | 1.1 |
| Round nose | 1.0 |
| Circular cylinder | 1.0 |
| Sharpe nose | 0.9 |
| Group of cylinders | 1.0 |

**Table 6.** Approach flow-angle correction factor ($K_2$) for the HEC-18 equation (from Richardson and others, 1993)
[L, pier length, in feet; a, pier width, in feet]

| Approach flow angle (degrees) | L/a=4 | L/a=8 | L/a=12 |
|---|---|---|---|
| 0 | 1.0 | 1.0 | 1.0 |
| 15 | 1.5 | 2.0 | 2.5 |
| 30 | 2.0 | 2.75 | 3.5 |
| 45 | 2.3 | 3.3 | 4.3 |
| 90 | 2.5 | 3.9 | 5.0 |

**Table 7.** Bed-condition correction factor ($K_3$) for the HEC-18 equation (from Richardson and others, 1993)
[ft, feet; N/A, not applicable]

| Bed condition | Dune height (H) (ft) | $K_3$ |
|---|---|---|
| Clear-water scour | N/A | 1.1 |
| Plane bed and antidune flow | N/A | 1.1 |
| Small dunes | 10>H>2 | 1.1 |
| Medium dunes | 30>H>10 | 1.1 to 1.2 |
| Large dunes | H>30 | 1.3 |

The correction factor $K_1$ for pier-nose shape should be determined using table 5 for angles of approach up to 5 degrees. For greater angles, $K_2$ dominates, and $K_1$ is considered to be 1.0. If pier length divided by pier width (*L/a*) is larger than 12, use *L/a* equal to 12 from table 6 as a maximum when determining $K_2$.

The normal pier width was used in the HEC-18 equation with $K_2$ equal to 1.0 for piers skewed to the approach flow. Using the normal pier width with $K_2$ equal to 1.0 in the HEC-18 equation probably is conservative (especially for spaced columns or piles with no connecting web wall) because a skewed pier's normal width usually does not produce as much scour as a pier of the same width that is not skewed. The flow approaching a skewed pier generally will not abruptly collide with the entire normal width of the pier, but will slide off the side of the pier, which will reduce the strong downward vortices and side eddies. Mostafa and others (1993) indicated that the effective normal width is about 85 percent of the actual normal width of a rectangular pier for skew angles ranging from 15 to 90 degrees. For angles less than 15 degrees, Mostafa suggested using the actual normal width.

Some of the piers in this report are two or more spaced columns on top of pile-supported footings, for which the effective normal pier width is probably less than 85 percent of the actual normal pier width. For certain angles of approach, the spacing would allow some of the approach flow to pass through the pier; whereas, a solid pier would obstruct all of the approach flow. As Richardson and others (1993) noted in HEC-18, the pier-scour depth depends on the spacing between the columns, and the correction factor for angle of approach is most likely smaller than for a solid pier. Raudkivi (1986) suggested that for cylindrical columns having five column-diameter spacing, the local scour could be reduced to about 1.2 times the scour at a single cylindrical column. If 1.2 is used for $K_2$ in the HEC-18 equation, then the effective normal width is about 76 percent of the largest possible normal width (two column diameters) for two cylindrical columns spaced five column-diameters apart.

Approach flow angles were greater than 0 degrees for 147 of the 190 measured pier-scour depths (77 percent). Of these 147 measurements, 83 (56 percent) were at near-rectangular piers, and 64 (44 percent) were at two or more spaced column or pile groups. Page 44 of HEC-18 does suggest using the projected normal pier width ($a'$) with $K_2$ equal to 1.0 for multiple columns spaced less than five pier diameters apart. For the Mississippi data, all of the columns or piles were spaced at about five pier diameters or less apart. Additional laboratory studies are necessary to provide guidance on the limiting approach flow angles for given distances between multiple columns beyond which multiple columns can be expected to function as solitary members with minimal influence from adjacent columns (Richardson and others, 1993).

For consistency within this report, $a'$ with $K_2$ equal to 1.0 was used for both the near-rectangular piers and the spaced column or pile groups. The use of $a'$ with $K_2$ equal to 1.0 for near-rectangular piers resulted in slightly larger computed pier-scour depths than using $a$ with $K_2$ from table 6. For the 83 measurements at near-rectangular piers, the computed pier-scour depths were 0.1 to 0.9 ft or 0.6 to 6.1 percent larger than the pier-scour depths computed by using $a$ with $K_2$ from table 6 and were an average of only 0.5 ft or 3.9 percent larger.

Computed pier-scour depths were compared to the measured pier-scour depths, which ranged from 0.6 to 20.4 ft. The HEC-18 equation predicted pier-scour depths ranging from 3.9 to 25.7 ft (fig. 9) with residuals (measured pier scour minus computed pier scour) ranging from -21.7 to 0.2 ft. The envelope-curve equation developed during this study predicted pier-scour depths ranging from 2.2 to 19.7 ft (fig. 10) with residuals ranging from -16.8 to 6.2 ft. The residual of 6.2 ft is for measurement 179, where some of the measured pier scour could have been caused by a jetty and stream bank, as previously described. Excluding measurement 179, residuals ranged from -16.8 to 0.5 ft. The envelope-curve equation predictions could be used for reasonable verifications of the HEC-18 pier-scour predictions, which are currently required in the design and maintenance of bridges in Mississippi.

## MEASURED TOTAL-SCOUR DEPTHS

Blodgett (1989) noted that total-scour depth at minimum-bed elevation (deepest scour) is important in bridge design because it is the worst case scenario. Fluctuation of minimum-bed elevation or total-scour depth observed through time is a good indication of bed stability. Scour depth at minimum-bed elevation is shown schematically in figure 11 for no lateral movement and for significant lateral movement of the channel. If there is significant lateral movement of the channel, total-scour depths larger than those at minimum-bed elevation could actually occur through time at an overbank pier. The lateral movement of the channel at sites 4, 6, 7, 8, 9, 11, 12, 13, 21, and 22 has been documented by Turnipseed and Smith (1992) and Turnipseed (1993, 1994).

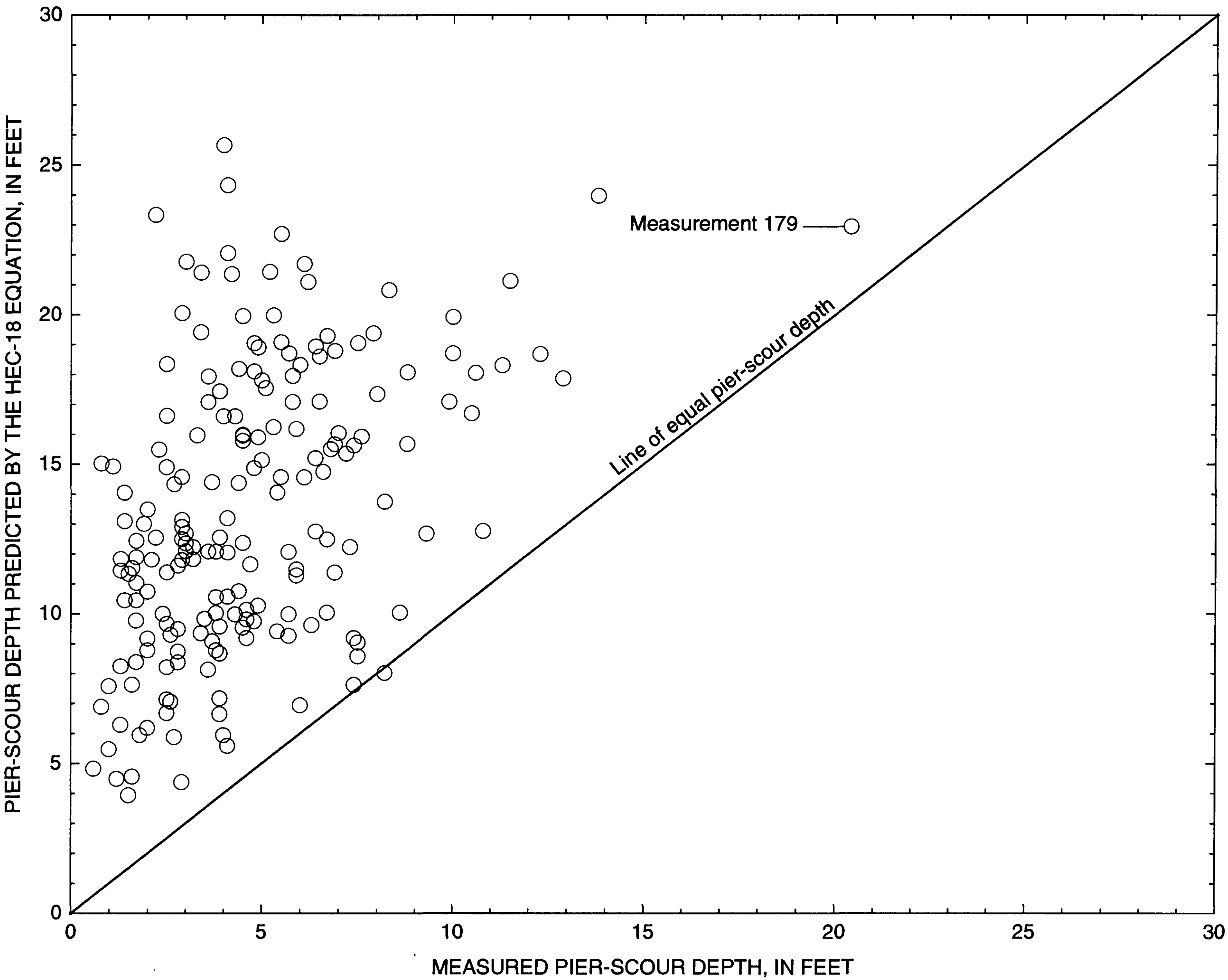


**Figure 9.** Relation between pier-scour depth predicted by the HEC-18 equation and measured pier-scour depth for selected bridge sites in Mississippi.

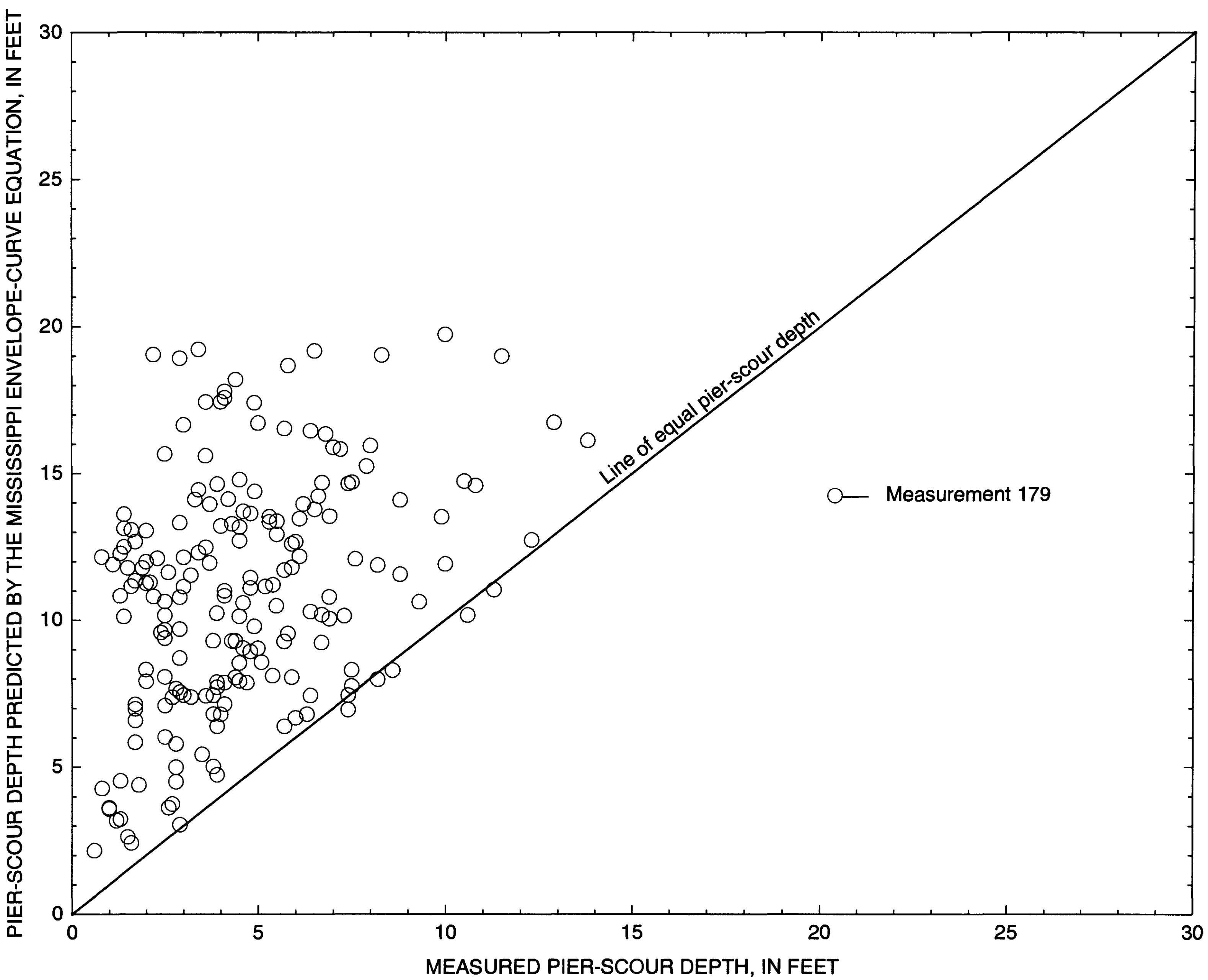


**Figure 10.** Relation between pier-scour depth predicted by the Mississippi envelope-curve equation and measured pier-scour depth for selected bridge sites in Mississippi.

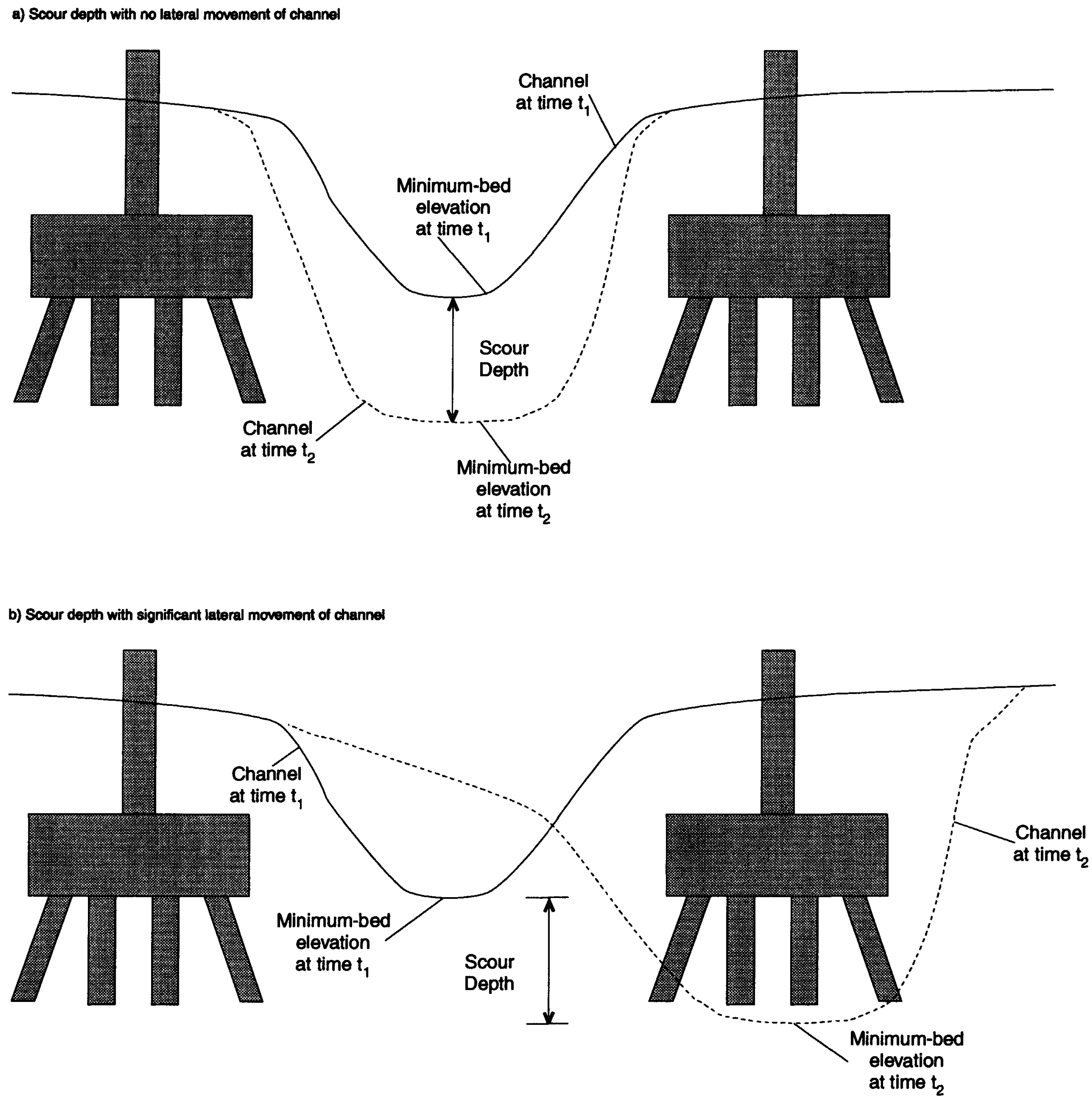


**Figure 11.** Scour depth at minimum-bed elevation (a) with no lateral movement and (b) with significant lateral movement of the channel.

Ground-penetrating radar was used during summer 1992 to determine total-scour depths during low-flow conditions at sites 1 to 4, 7 to 9, 11 to 13, 15 to 18, 20, and 21 and also at three other bridge sites along the Pearl River as requested by the MDOT. These sites were thought to be representative of streams in Mississippi with the greatest potential for scour. The ground-penetrating radar was useful in detecting stratified subsurface layers that could inhibit scour. The radar worked well where there was a subsurface interface consisting of either sand overlying gravel, or sand and gravel overlying clay. Where sites had submerged debris, the radar signal was distorted. If a scour interface was determined, the stream hydraulics associated with the scour interface had to be estimated, but this was outside the scope of the study. From analyses of the ground-penetrating-radar data completed to date (1994), as much as 24 ft of total scour was indicated by infilling upstream of sites 12 and 13. For the bridge-scour sites in Mississippi, scour detected by the ground-penetrating radar may not be representative of a single flood, but of many floods through time.

Minimum-bed elevations were obtained from 2,965 discharge measurements obtained during 1938-94 at the 22 selected bridge-scour sites in Mississippi (table 8). At each site, the lowest minimum-bed elevation was subtracted from the highest minimum-bed elevation to obtain total-scour depth at minimum-bed elevation. Total-scour depth from these measurements represents mostly general and constriction scour, and possibly include some pier scour, depending on the proximity of the soundings to the bridge piers. The total-scour depth at minimum-bed elevation for sites with more than 20 discharge measurements ranged from 5.2 ft (site 5) to 29.8 ft (site 21) (table 8).

Data for site 5 are presented in this report to illustrate a stable channel bed at a Mississippi bridge site. No pier-scour measurements were obtained at site 5 because the site was identified as having a low scour potential. The piers at site 5 are near midbank of each bank and, therefore, do not significantly influence scour of the main channel. The streambed at this site consists of sand and some gravel with a $D_{50}$ of 0.00105 ft overlying a resistant siltstone and sandstone of the Basic City Shale Member of the Tallahatta Formation (M.J. Wright, MDOT, written commun., 1994). For the period of record, the lowest minimum-bed elevation was 267.5 ft (table 8) with most minimum-bed elevations between 268 and 269 ft. Therefore, minimum-bed elevation varied by only 1 to 2 ft except for the period of the late 1950's to the late 1970's when there likely was infilling to the highest minimum-bed elevation of 272.7 ft (fig. 12).

Sites 1, 21, and 22 have the largest total-scour depths at minimum-bed elevation (table 8). The large variations in bed level at these sites are shown in figures 13, 14, and 15, respectively. The maximum recurrence interval of the measured discharges at these three sites is only 15 years. Therefore, the total-scour depths during extreme flooding could be larger than the total-scour depths shown in this report.

The 29.0 ft of total scour at minimum-bed elevation at site 1 (table 8) was unexpected because there had been no known scour problems at the site. Site 1 is on a streambed consisting of sand and gravel and is located downstream of the mouth of Bouie River. Gravel mining on Bouie River upstream of its mouth probably is contributing to the variations in the minimum-bed elevation at this site (fig. 13). Only one pier-scour measurement was obtained at this site, and that measurement did not indicate a significant pier-scour problem.

The 29.8 ft of total scour at minimum-bed elevation at site 21 (table 8) was expected because this site has known scour problems. Site 21 is on a streambed consisting of sand, which degraded about 15 ft between 1941 and 1974 (Wilson, 1979). By plotting the annual minimum stages through time, the bed at this

**Table 8.** Summary of total-scour data collected at selected bridge sites in Mississippi
[ft, feet; $ft^3/s$, cubic feet per second; yrs, years; <, less than]

| Site no. | Period of record | No. of measurements | Minimum-bed elevation (ft) | | Total-scour depth (ft) | Stage (ft) | | Discharge ($ft^3/s$) | | Recurrence interval (yrs) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Highest | Lowest | | Maximum | Minimum | Maximum | Minimum | Maximum | Minimum |
| 1 | 1939-94 | 201 | 123.1 | 94.1 | 29.0 | 147.1 | 120.1 | 59,500 | 514 | 15 | <2 |
| 2 | 1968-94 | 100 | 71.7 | 58.4 | 13.0 | 101.8 | 73.3 | 65,900 | 625 | 15 | <2 |
| 3 | 1943-90 | 10 | 51.7 | 45.0 | 6.7 | 86.3 | 59.9 | 85,100 | 979 | 20 | <2 |
| 4 | 1939-93 | 409 | 43.5 | 25.3 | 18.2 | 73.8 | 44.2 | 107,000 | 624 | 35 | <2 |
| 5 | 1939-94 | 197 | 272.7 | 267.5 | 5.2 | 294.1 | 272.3 | 26,000 | 106 | 10 | <2 |
| 6 | 1938-94 | 383 | 53.6 | 40.8 | 12.8 | 84.6 | 59.1 | 73,400 | 153 | 35 | <2 |
| 7 | 1961-94 | 153 | 317.3 | 299.2 | 18.1 | 343.5 | 319.3 | 90,000 | 205 | 500 | <2 |
| 8,9 | 1967-91 | 14 | 242.9 | 236.3 | 6.6 | 276.0 | 259.4 | 55,300 | 5,950 | 9 | <2 |
| 10 | 1939-94 | 212 | 181.5 | 173.0 | 8.5 | 214.6 | 184.3 | 59,000 | 270 | 10 | <2 |
| 11 | 1939-94 | 453 | 155.7 | 143.2 | 12.5 | 190.7 | 162.7 | 97,700 | 407 | 100 | <2 |
| 12,13 | 1948-91 | 111 | 112.8 | 104.5 | 8.3 | 143.4 | 118.0 | 122,000 | 844 | 400 | <2 |
| 14 | 1942-94 | 171 | 277.8 | 263.2 | 14.6 | 297.1 | 269.2 | 24,300 | 5.8 | 10 | <2 |
| 15,16 | 1961-91 | 5 | 125.2 | 120.2 | 5.0 | 161.2 | 146.4 | 63,000 | 3,020 | 20 | <2 |
| 17 | 1939-94 | 120 | 220.3 | 213.3 | 7.0 | 236.2 | 218.4 | 43,600 | 251 | 50 | <2 |
| 18 | 1953-90 | 11 | 284.8 | 280.2 | 4.6 | 300.4 | 288.7 | 22,400 | 1,550 | 50 | <2 |
| 19,20 | 1942-71 | 90 | 186.6 | 176.6 | 10.0 | 203.0 | 186.9 | 61,100 | 267 | 15 | <2 |
| 21 | 1951-94 | 167 | 108.8 | 79.0 | 29.8 | 129.8 | 100.2 | 138,000 | 224 | 15 | <2 |
| 22 | 1942-94 | 158 | 98.5 | 71.7 | 26.8 | 114.6 | 97.6 | 42,500 | 28.0 | 6 | <2 |

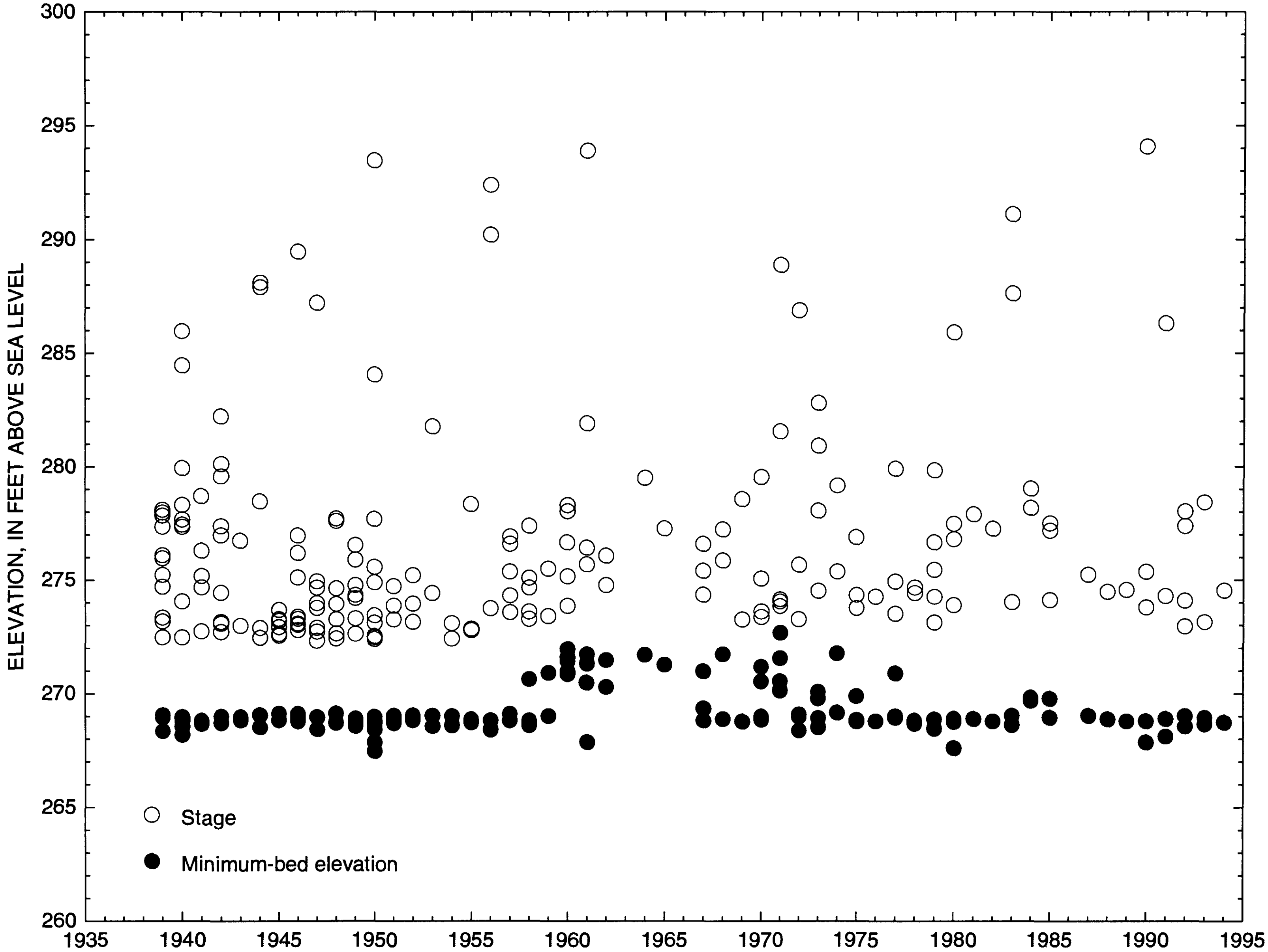


**Figure 12.** Relation of measured stage and minimum-bed elevation to time for Chunky River at U.S. Highway 80 near Chunky (site 5), Mississippi.

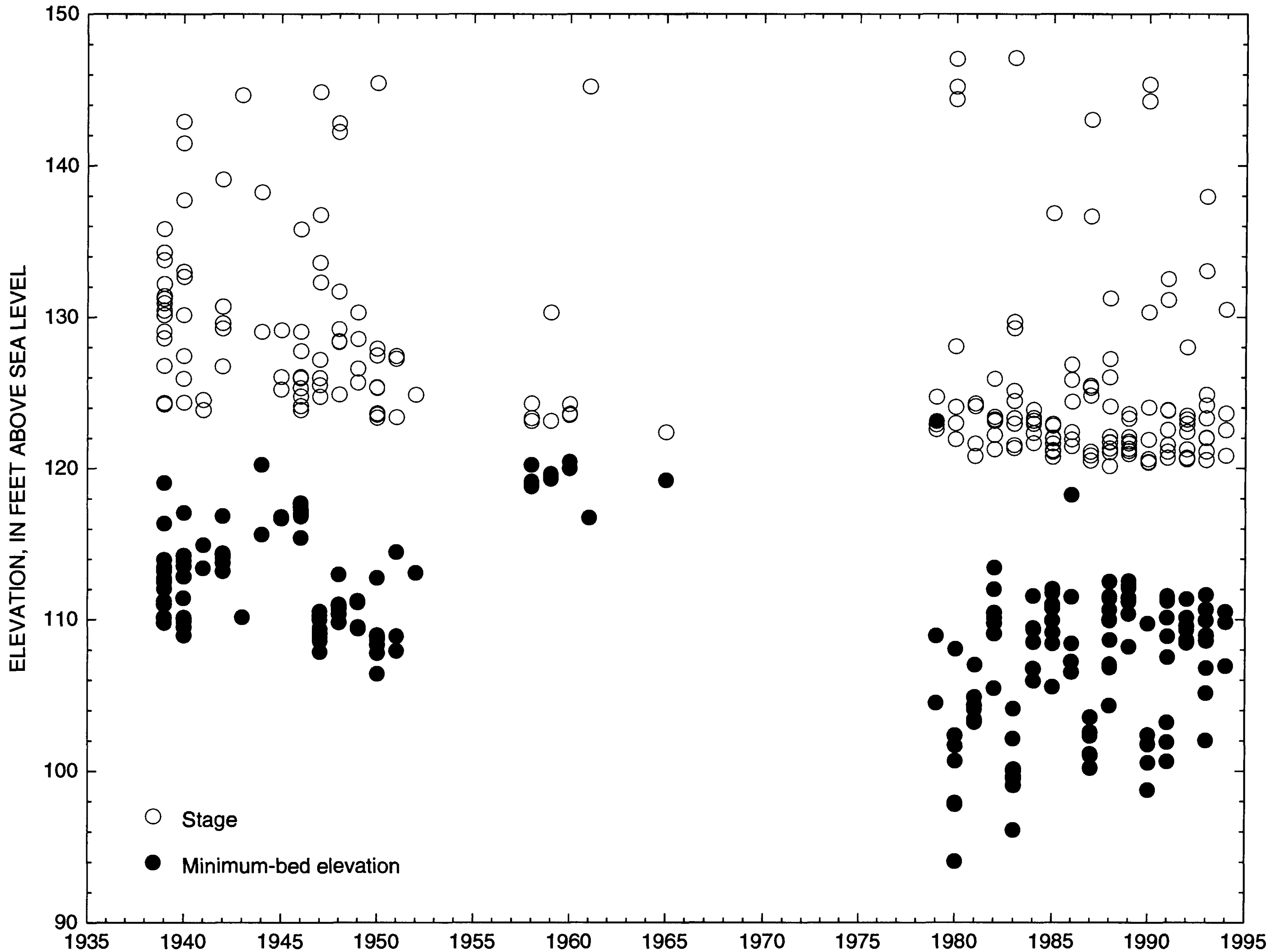


**Figure 13.** Relation of measured stage and minimum-bed elevation to time for Leaf River at U.S. Highway 11 at Hattiesburg (site 1), Mississippi.

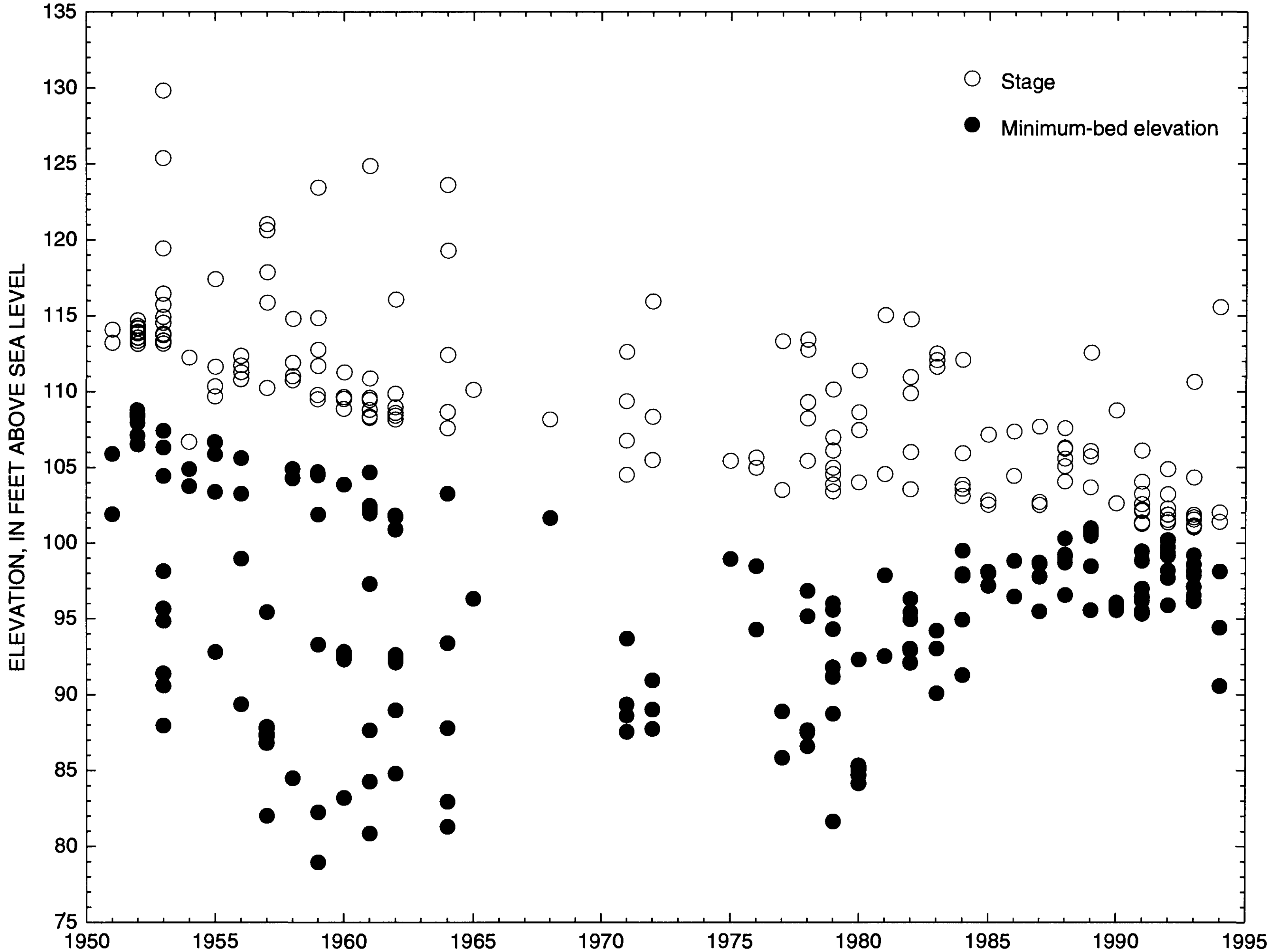


**Figure 14.** Relation of measured stage and minimum-bed elevation to time for Homochitto River at State Highway 33 at Rosetta (site 21), Mississippi.

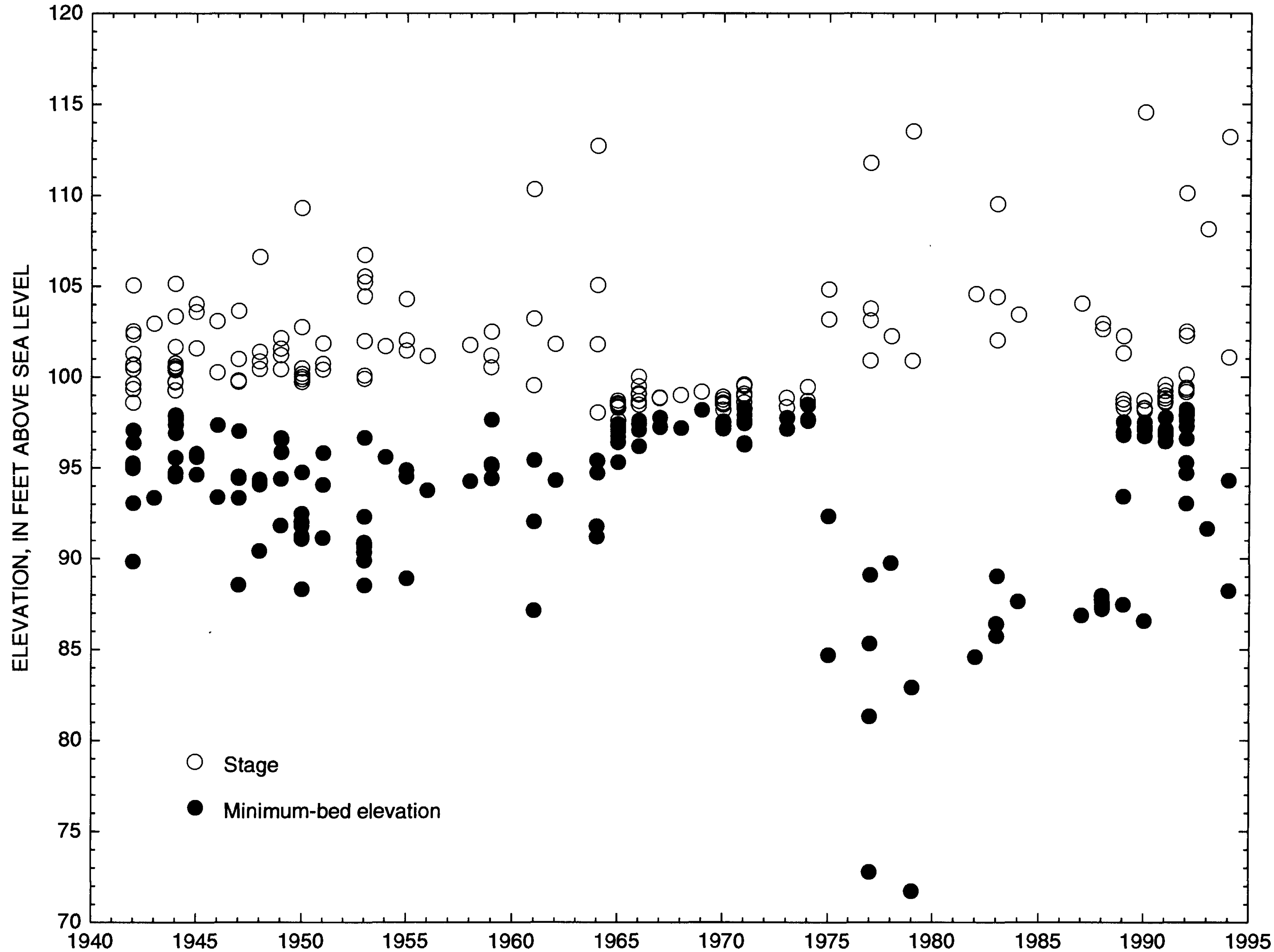


**Figure 15.** Relation of measured stage and minimum-bed elevation to time for Buffalo River at U.S. Highway 61 near Woodville (site 22), Mississippi.

site has fluctuated and lowered only about 1 ft between 1974 and 1994, and the degradation appears to have ceased. Widening is the dominant process occurring at this site. The channel at this site has moved laterally about 790 ft northward between 1953 and 1990 (Turnipseed, 1994). As much as 49 ft of total scour, including lateral erosion, has occurred on the north overbank. As much as 25 ft of variation in minimum-bed elevation occurred in a given year in the 1950's and 1960's, but since the 1960's, the fluctuation in minimum-bed elevation decreased (fig. 14).

Minimum-bed elevations shown in figure 14 are for two bridges at site 21. A 600-ft-long bridge was in place until 1974, when it collapsed. This bridge was replaced with a 1,500-ft-long bridge that was completed in 1978. The minimum-bed elevation fluctuated more at the 600-ft-long bridge probably because the channel was significantly narrower than it is today and the bridge consisted of shorter spans. The 600-ft-long bridge consisted of 60- and 80-ft-long spans; whereas, the 1,500-ft-long bridge consists of 250-ft-long spans. The shorter bridge spans allowed more debris piles and bridge piers to obstruct the approach flow. Available discharge measurements indicated significant overlapping of the pier-scour holes at the 600-ft-long bridge.

The 26.8 ft of total scour at minimum-bed elevation at site 22 (table 8) was expected because this site has known scour problems. However, no significant degradation has occurred at this site. Site 22 is on a streambed consisting of sand. Most of the lateral movement of the channel at this site has occurred away from the bridge (Turnipseed, 1994). The maximum pier-scour depth of 20.4 ft for the Mississippi pier-scour data was obtained at this site in 1977 and is indicated in figure 15 by the lowest minimum-bed elevations shown in 1977 and 1979. As previously described, the measured pier-scour depth of 20.4 ft was affected by a flow jetty and the left (south) stream bank.

Two flow jetties were installed on the left stream bank at site 22. The first jetty was installed in 1968, and the second jetty, which provided a smoother transition for flows through the bridge, was installed in summer 1979. Between 1968 and 1977, the largest measured discharge was only 4,710 $ft^3/s$. Therefore, the effects on the streambed by the jetty installed in 1968 were not indicated until 1977, when the measured discharge was 34,500 $ft^3/s$. The smoother transition provided by the jetty installed in 1979 appears to be indicated by the higher minimum-bed elevations after 1979 (fig. 15).

## SUMMARY

This report summarizes scour data collected during 1938-94 at 22 bridge sites in Mississippi. The methods used to measure scour and selected characteristics at each site are described. Selected hydraulic and bridge-geometry characteristics are presented. The drainage area of the bridge-scour sites ranged from 60.8 to 5,720 $mi^2$, and the slope in the vicinity of each site ranged from 0.00011 to 0.00163 ft/ft. At most sites, the bed material consisted of sand and(or) gravel, and in some cases, the sand and(or) gravel was underlain by a clay stratum, which is thought to affect the measured scour depths. Recurrence intervals of measured discharges ranged from less than 2 to about 500 years.

Pier-scour data were collected during high flows at sites representing various hydraulic, bed-material, and pier-geometry characteristics. Measured pier-scour depth ranged from 0.6 to 20.4 ft, with scour-hole top width, when determined, ranging from 8 to 180 ft. Approach-flow depth ranged from 2.3 to 36.6 ft, approach-flow velocity ranged from 1.3 to 10.4 ft/s, and approach-flow skew ranged from 0 to 46 degrees. Median bed-material size ranged from 0.00092 to 0.02464 ft, and the geometric standard deviation of the bed-material sizes or the gradation coefficient ranged from 1.3 to 8.3. Some of the measured pier-scour depths were affected by the areal extent of the pier footing. Only 12 (6 percent) of the 190 pier-scour depths were greater than 1.1 times the normal pier width. An envelope-curve equation for the Mississippi pier-scour data was developed by relating pier-scour depth divided by normal pier width to approach-flow depth divided by normal pier width.

All of the Mississippi pier-scour depths were within 2.3 times the normal pier width, which agreed with previous research. Measured pier-scour depths were as much as 2.24 times a normal pier width of 3.3 ft. However, for pier widths greater than about 4 ft, measured pier-scour depths were significantly less than 2.3 times the normal pier width.

Debris piles and bed-material characteristics probably affected some of the measured pier-scour depths. Debris piles significantly obstructed more approach flow than the pier for some measurements, and the normal width of the largest debris pile was as much as 1.5 times as large as the actual pier width. At several sites, measured pier-scour depths probably were affected by heterogeneous material, primarily where a clay stratum was overlain by sand and(or) gravel. The range of measured pier-scour depths for a respective median bed-material size generally decreased as the median bed-material size increased and as the gradation coefficient increased. Limited data indicate the pier-scour depths decreased as shear strength of the clay increased.

Critical velocity was calculated and compared with the measured velocity of the flow approaching the bridge piers to determine whether the measured pier-scour depth was live-bed or clear-water scour. Using Neill's equation, some of the measured pier-scour depths were indicated as clear-water scour, but most were indicated as live-bed scour. For some of the pier-scour measurements that indicated clear-water scour, the median bed-material size used to determine live- or clear-water scour was perhaps not representative of the entire bed material at the bridge site, and therefore, the measurement could have actually been live-bed scour.

Computed pier-scour depths were compared to the measured pier-scour depths. Pier-scour depths were computed using the pier-scour prediction equation currently (1994) recommended in the Federal Highway Administration Hydraulic Engineering Circular No. 18 (HEC-18) and the envelope-curve equation developed for Mississippi pier-scour data during this study. The HEC-18 equation predicted pier-scour depths ranging from 3.9 to 25.7 ft with residuals (measured pier-scour depth minus computed pier-scour depth) ranging from -21.7 to 0.2 ft. The envelope-curve equation developed during this study predicted pier-scour depths ranging from 2.2 to 19.7 ft with residuals ranging from -16.8 to 6.2 ft. The residual of 6.2 ft for the envelope-curve equation developed during this study was at a site where some of the measured pier scour could have been caused by a jetty and stream bank. Excluding this measurement, residuals ranged from -16.8 to 0.5 ft. The envelope-curve equation predictions could be used for reasonable verifications of the HEC-18 pier-scour predictions, which currently are required in the design and maintenance of bridges in Mississippi.

Total-scour depths were determined by using ground-penetrating radar during low-flow conditions and by obtaining minimum-bed elevations from 2,965 discharge measurements obtained during 1938-94. As much as 24 ft of total scour was indicated by infilling approximated from ground-penetrating-radar data. The total-scour depth at minimum-bed elevation for sites with more than 20 discharge measurements ranged from 5.2 to 29.8 ft. The total-scour depth of 5.2 ft at minimum-bed elevation was on a streambed consisting of sand and some gravel overlying a resistant siltstone and sandstone. The total-scour depth of 29.8 ft at minimum-bed elevation was in a channel with a streambed consisting of sand that has degraded about 15 ft. Also, the channel at this site has moved laterally about 790 ft northward causing as much as 49 ft of total scour on the overbank.

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