MONITORING SCOUR AT THE STATE HIGHWAY 15 BRIDGE ACROSS THE LEAF RIVER AT BEAUMONT, MISSISSIPPI

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Introduction

Scour of channel-bed material around bridge piers and in the vicinity of bridges is a potential problem that must be considered when constructing bridges spanning waterways. Erosive action of flowing water may expose or undermine bridge-pier and bridge-abutment foundations and thereby induce structural failure. Accurate estimates of potential scour are essential in the design, construction, and maintenance of bridges. The collection of scour data at bridge sites during floods provides a better understanding of scour and provides the information necessary to improve methods that can be used in bridge design to estimate scour. Because of the difficulty of obtaining scour data around bridges during floods, few data have been collected.

The term "scour," as used in this report, is defined as the lowering of the channel bed 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, a phenomenon that is a cause of concern for alluvial streams in Mississippi, can be attributed to three interrelated phenomena:

General scour: progressive degradation of the channel bed caused by natural processes or by changes in channel control that may occur over a long channel reach and, possibly, over many years. General scour could also be a temporary fluctuation about some mean level. This type of scour may occur in a channel, even if no bridge is present.

Constriction scour: channel-bed erosion caused by increased flow velocities through a bridge opening due to the decreased flow area formed by the bridge, its approach embankments, and its piers.

Local scour: erosion of the channel bed caused by local disturbances in the flow, such as vortices and eddies in the vicinity of piers and abutments.

Although these components of scour are not completely independent, general practice in bridge design is to compute each component of scour separately, using equations based on scale-model laboratory measurements, and then combine these predicted scour depths to estimate the total scour depth at a bridge site. Scour data at bridge sites are needed to verify and improve the scour-predicting equations. However, in evaluating field data for a natural stream at a bridge site, it is usually difficult to identify whether the scour measured is general, constriction, or local scour. Measurements of scour depth are complicated by channel-bed conditions, debris, effects of multiple piers, flow distribution, and definition of the reference elevation used to determine scour. Also, measured scour depths could be partially due to extreme floods that have occurred prior to data collection and, therefore, total scour depths could be incorrectly associated with measured floods.

Purpose and Scope: In 1990, the U.S. Geological Survey (USGS), in cooperation with the Mississippi State Highway Department (MSHD), began a 4-year study to collect bridge-scour data. During 1990, scour data were collected before, during, and after floods at 15 stream crossings in Mississippi. This report describes only the results of scour data collected from January 28 to September 10, 1990, at the State Highway 15 bridge across the Leaf River at Beaumont, Mississippi. Eight onsite scour measurements were collected during two floods having 5- to 10-year recurrence intervals. Channel cross sections for these two floods were compared to a channel cross section surveyed in 1937 (prior to bridge construction) and to a cross section from a discharge measurement made in 1943. General, constriction, or local scour was determined from each channel cross section. After sufficient data have been collected, these data will be compared to estimates determined from the scour-prediction equations currently being used in bridge design by the Federal Highway Administration (1988).

General Description of Study Site: The study site is located at the State Highway 15 bridge across the Leaf River 0.9 mi (mile) north from intersection of U.S. Highway 98 and State Highway 15 at Beaumont, Mississippi. The flood plain is about 1.7 mi wide and is constricted by a 1,030-ft (foot) long main-channel bridge and a 380-ft long relief bridge in the roadway embankment (Fig. 1). The drainage area of Leaf River at State Highway 15 is 3,010 mi2 (square miles);

the length of the channel upstream of the crossing is about 153 mi, and the average channel slope (between 10 and 85 percent of the length upstream of the crossing) is about 2.2 ft/mi (feet per mile). Average channel and valley slopes are about 1.0 ft/mi in the vicinity of the crossing. The highway alignment is skewed about 10 degrees from normal to the channel and flood plain. The water flows through a 90 degree bend about 0.3 mi upstream from the State Highway 15 crossing, but the main channel is fairly straight and uniform in width through the bridge opening.

The main-channel bridge is supported by timber pile bents on the flood plain and four concrete square-nosed piers in the channel. The two piers near the edges of the channel have an average width of 2.8 ft, and the other two piers in the channel have an average width of 3.2 ft.

The right (south) bank is composed of sand and clay, but the left (north) bank is composed mostly of loose sand. (The left and right convention used for cross sections in this report is defined as the direction as viewed when facing downstream.) The channel bed consists of loose to dense sand overlying a hard silt and clay stratum. It is uncertain where the sand and clay interface is located below the bed because no soil borings were taken in the channel (MSHD, written commun., 1989). No long-term instability (degradation or aggradation) is evident for the channel bed. The right bank appears to be fairly stable, but the left bank has experienced some instabilities.

Data Collection

Extent of Data: Scour data were collected in 1990 by the USGS near the peak discharge and during the falling limb (decreasing discharge) of the January 28 flood as well as during the rising limb (increasing discharge) and at the peak discharge of the February 21 flood. Data were also collected during low flows on March 27 and September 10 to determine bed elevations when sediment transport was minimal. The USGS also made low-flow discharge measurements in 1965, 1976, and 1978. Other agencies that have collected streamflow data at this site include the U.S. Army Corps of Engineers, which obtained intermittent stages and discharges from January 1941 to February 1945, and the National Weather Service, which obtained daily stages from January 1941 to April 1976. In 1943, the U.S. Army Corps of Engineers measured a discharge of 85,100 ft3/s (cubic feet per second), which is the largest available discharge measurement with a recurrence interval of about 25 years. Stage data and other elevations used in this report are referenced to National Geodetic Vertical Datum of 1929 (a datum derived from a general adjustment of first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929) and referred to in this report as sea level.

During the floods of January and February 1990, cross sections were sounded at the upstream and downstream sides of the main channel bridge, at the upstream side of the bridge piers, and also about 50 ft downstream from the main channel bridge. Stage, water depth, and angle and magnitude of the approach velocity were measured to determine channel-bed elevations and corresponding discharges for scour conditions at the bridge. Discharge measurements were used to develop a stage-discharge relation at the downstream side of the bridge so that stage readings could be converted to discharge without having to make continuous discharge measurements.

Channel cross sections and longitudinal profiles away from the bridge were not measured during the floods but were measured when it was possible to work safely from a boat. Seven cross sections were sounded in the channel reach between about 1,300 ft upstream and about 950 ft downstream from the main channel bridge (Fig. 1). Bridge geometry, some channel cross sections, and a soils foundation report (MSHD, written commun., 1989) were obtained from the MSHD. Photographs were taken at the site to document debris and flow conditions.

Description of Equipment: Soundings of water depth and measurements of velocity for determining discharge were made using standard streamflow-gaging procedures as described by Rantz and others (1982). Depth and vertical position in the water were measured by suspending a 100-, 150-, or 200-pound Columbus sounding weight which was used to keep the suspended Price AA current meter and cable fairly stationary in the water. A truck-mounted winch was used to lower and raise the meter and weight.

Soundings to the channel bed to measure channel geometry were obtained with an Eagle Model Mach 1 Graph recording fathometer (the use of trade or product names in this report is for identification purposes only and does not constitute endorsement by the USGS). Transducers used with the fathometer produced an 8-degree beam width, allowing close access to bridge piers without creating side echoes. Use of the fathometer made soundings possible at a large number of points across the cross section.

During floodflows, the transducer was attached to the bottom of the sounding weight which was lowered into the water from a truck-mounted winch and towed through the water as the truck was driven slowly across the bridge. For the soundings about 50 ft downstream from the bridge, a flotation device was connected to the cable so that the transducer could be floated downstream. During low flows, the transducer was attached at or near the bow of a boat and the depths were recorded as the boat traversed the cross section or longitudinal profile.

Results of Surveys

Channel cross-section surveys were made at seven different locations (Fig. 1) from January 28 to September 10, 1990. Cross sections were also obtained from MSHD bridge plans and from selected discharge measurements made at the upstream side of the bridge (cross section 4). Two approximate thalweg profiles (longitudinal line of continuous maximum descent on the channel bed) were obtained for the channel reach between cross sections 1 and 7 (Fig. 2). Between the farthest cross section upstream (7) and the cross section at the upstream side of the bridge (4), the thalweg elevation increases in the downstream direction. Between cross section 4 and cross section 1, which is the farthest cross section downstream, thalweg elevation is relatively uniform, except for a scour hole downstream of cross section 2. Thus, the depth of water decreases in the downstream direction toward the bridge, and the decrease in depth is characteristic of non-uniform flow. The decreasing depth is caused by the water flowing through a natural constriction at the 90 degree bend, just upstream from cross section 7 (Fig. 1). The flow velocities are increased at the channel bend and, thus, the channel bed is scoured. The material scoured from the channel bend is then deposited downstream as velocities decrease and become more uniform across the channel width. The two thalweg profiles generally have the same trends with scour and fill at various locations (Fig. 2). Some differences may be attributed to the difficulty in obtaining the profiles in the same location. For this report, therefore, the profiles are considered approximate.

General Scour: Three surveys of cross sections 1, 5, and 7 (Figs. 1 and 2) were made in 1990 to document general scour. Selected characteristics describing general scour at these cross sections are presented in Table 1. Scour at these cross sections is considered to be representative of only temporary fluctuations about some mean value because no long-term trend (degradation or aggradation) is evident for this river. General scour at each cross section was calculated based on the February 13, 1990, average- and minimum-bed elevations. Scour at the minimum bed (maximum scour) is very important in bridge design because it is the worst case situation (Blodgett 1989). The maximum stage of the three surveys was about 8 ft below bankfull stage on February 13, 1990. The maximum difference in stage between the three surveys at cross sections 1, 5, and 7 averaged 14.4 ft. Average-bed scour at the three cross sections ranged from 1.0 to 4.4 ft (both at cross section 7). Maximum scour ranged from -2.4 to 1.9 ft (Table 1). Negative scour is indicative of fill. The average-bed elevation was 1.2 to 3.2 ft higher than the minimum-bed elevation for cross sections 1 and 5 and 6.4 to 13.2 ft higher than the minimum-bed elevation for cross section 7.

The channel-bed geometry of cross section 7 is substantially different from the other sections because the geometry is affected by the upstream channel bend (Figs. 1 and 2). Between February 13 and September 10, scour lowered the average-bed elevation 4.4 ft, but the minimum bed elevation increased 2.4 ft at section 7 (Table 1). These data are limited, and as suggested by Colby (1964), the scour data at a cross section may not be representative of scour throughout the channel reach.

Constriction Scour: Cross sections 2, 3, and 4 were used to document constriction scour at the bridge (Table 2). The upstream side of the bridge (cross section 4) was sounded with both a fathometer and a sounding weight on January 28 and February 21. The sounding weight, used to obtain depth and velocity observations for the discharge measurements, probably penetrated the channel bed and indicated depths greater than those obtained using the fathometer. Average and maximum flow velocities for the channel were 6.3 and 9.3 ft/s (feet per second) for January 28 and 6.5 and 9.5 ft/s for February 21.

To be consistent with the general scour estimates (Table 1), the average and minimum-bed elevations on February 13, 1990, were also used to calculate scour at cross sections 2, 3, and 4 (Table 2). Average bed scour ranged from -0.9 to 4.5 ft, and scour at minimum bed ranged from -1.4 to 8.1 ft. Scour at minimum bed may be caused by local scour processes. Maximum scour was obtained on March 23, 1943, during the largest discharge measurement, and average and maximum flow velocities for the channel were 7.1 and 10.8 ft/s, respectively.

Most of the average bed elevations obtained in 1943 and in 1990 for sections 2, 3, and 4 are higher than the 1937 elevation [scaled from MSHD bridge plans, dated 1937 (prior to bridge construction)]. If the scour due only to bridge constriction was substantial, the 1937 average bed elevation should typically be one of the highest. The channel geometry at cross section 4, obtained in 1937 and from the two largest discharge measurements made in 1943 and 1990, are plotted in Figure 3. There are substantial irregularities in the channel bed for the two largest discharge measurements made at cross section 4 after 1937. The minimum-bed elevation for all three observations at cross section 4 is at a different location (Fig. 3). The minimum-bed elevation is at piers for both discharge measurements and is near the base of the right bank for the 1937 cross section. The 1943 cross section has the lowest bed elevation at cross section 4. The 1943 average bed is only 0.8 ft lower than the 1937 average bed, but the 1943 minimum bed is 8.4 and 4.8 ft lower than the 1937 average and minimum bed, respectively (Table 2). This suggests that most of the scour at the bridge was probably local scour at the bridge piers.

In comparing general scour (Table 1) with constriction scour (Table 2), only the February 13, March 27, and September 10, 1990, surveys are concurrent. For these concurrent surveys, the constriction scour at cross sections 2, 3, and 4 is not substantially greater than the general scour presented for sections 1 and 5. Approximate thalweg profiles (Fig. 2) do not indicate a scour hole at the bridge, which also suggests that constriction scour at the bridge is not substantially greater than general scour through the channel reach. These concurrent surveys were made when discharges were much less than the peak discharges and the depth of scour at the bridge on these dates may have been reduced by the deposition of material during periods of relatively low velocity. For the peak discharges, constriction scour may be substantially different from general scour, but because of the limited data, this is uncertain.

Local Scour at Bridge Piers: Estimates of local scour depths near a pier may vary considerably, depending on the method chosen to interpret channel-bed geometry at the bridge. Blodgett (1989) presented six possible methods for defining a reference-plane (bed) elevation; he considered the typical bed elevation adjacent to the scour hole to be the most accurate reference-plane elevation for determining local scour depths. Consequently, local scour depths for this report were determined, where possible, using the typical bed elevation adjacent to the scour hole on the upstream side of the bridge at the time of the measurement.

Reference-bed elevation, pier-bed elevation (local minimum bed in proximity of pier), and scour-hole depth are presented, where possible, for each bridge pier (Table 3). For all four piers, reference-bed elevation ranged from 49.7 to 60.4 ft, pier-bed elevation ranged from 43.8 to 68.6 ft, and scour-hole depth ranged from 0.8 to 9.3 ft. These large ranges indicate that the channel bed at the bridge piers fluctuates substantially. The reference-bed elevations at each pier were greater than the average-bed elevations shown in Table 2, except at piers 2 and 4. For pier 2, all reference-bed elevations were less than average-bed elevations. For pier 4, reference-bed elevations were greater than average-bed elevations, except on February 1 and 20, 1990, when the reference-bed elevations were slightly less than average-bed elevations.

The pier-bed elevations for 1937 (prior to bridge construction) were the highest elevations measured at piers 1 and 4. For a comparison between conditions prior to and after bridge construction, the 1937 bed scoured a total of 8.9 ft at pier 1, 6.5 ft at pier 2, 7.6 ft at pier 3, and 17.1 ft at pier 4. Piers 1 and 4 are located near the base of the right and left banks, respectively. The right bank appears to have experienced some basal erosion, but the top of the bank has not substantially retreated. The top of the left bank has retreated about 45 ft, however. Thus, the comparisons between the 1937 elevations and the minimum pier-bed elevation are substantially distorted by a combination of bed and bank erosion at piers 1 and 4 (Fig. 3).

The depth of the scour hole is very dependent on the reference-bed elevation at the time of the measurement (Table 3). The minimum-bed elevation (43.8 ft) was recorded at pier 2 on March 23, 1943, when the reference-bed elevation was 49.7 ft; thus, the scour-hole depth was about 5.9 ft. However, there are five scour-hole depths for pier 3 that are greater than 5.9 ft, and one for pier 4 that is greater than 5.9 ft. The maximum scour-hole depth of 9.3 ft was recorded on January 28, 1990, at pier 3 using a reference-bed elevation of 59.9 ft (4.4 ft higher than the reference-bed elevation sounded with a weight). The weight possibly penetrated the loose-sand surface which was being disturbed by water turbulence because of a tree caught on pier 3.

Conclusions

During the large flood of 1943, the channel-bed elevation in the vicinity of the State Highway 15 bridge across the Leaf River at Beaumont, Mississippi, averaged about 0.8 ft lower than the average-bed elevation prior to bridge construction, and minimum-bed elevation was about 4.8 ft lower. Data collected in 1990 during periods of moderate discharges indicate the channel bed is susceptible to general scour. Based on the limited data, the general scour is not substantially different from the constriction scour that occurs at the bridge. Local scour at the bridge piers is the maximum component of total scour in these measurements. Local scour of 9.3 ft at pier 3 has been measured. Total scour of 17.1 ft at pier 4 is due mostly to erosion of the left (north) bank which has eroded laterally about 45 ft at the top of the bank.

Data in this report are an example of the type of data that have been collected in the first year of a 4-year study. As more data are collected at bridge sites, a better understanding of scour processes may lead to improved methods of predicting scour in bridge design and evaluation.

References

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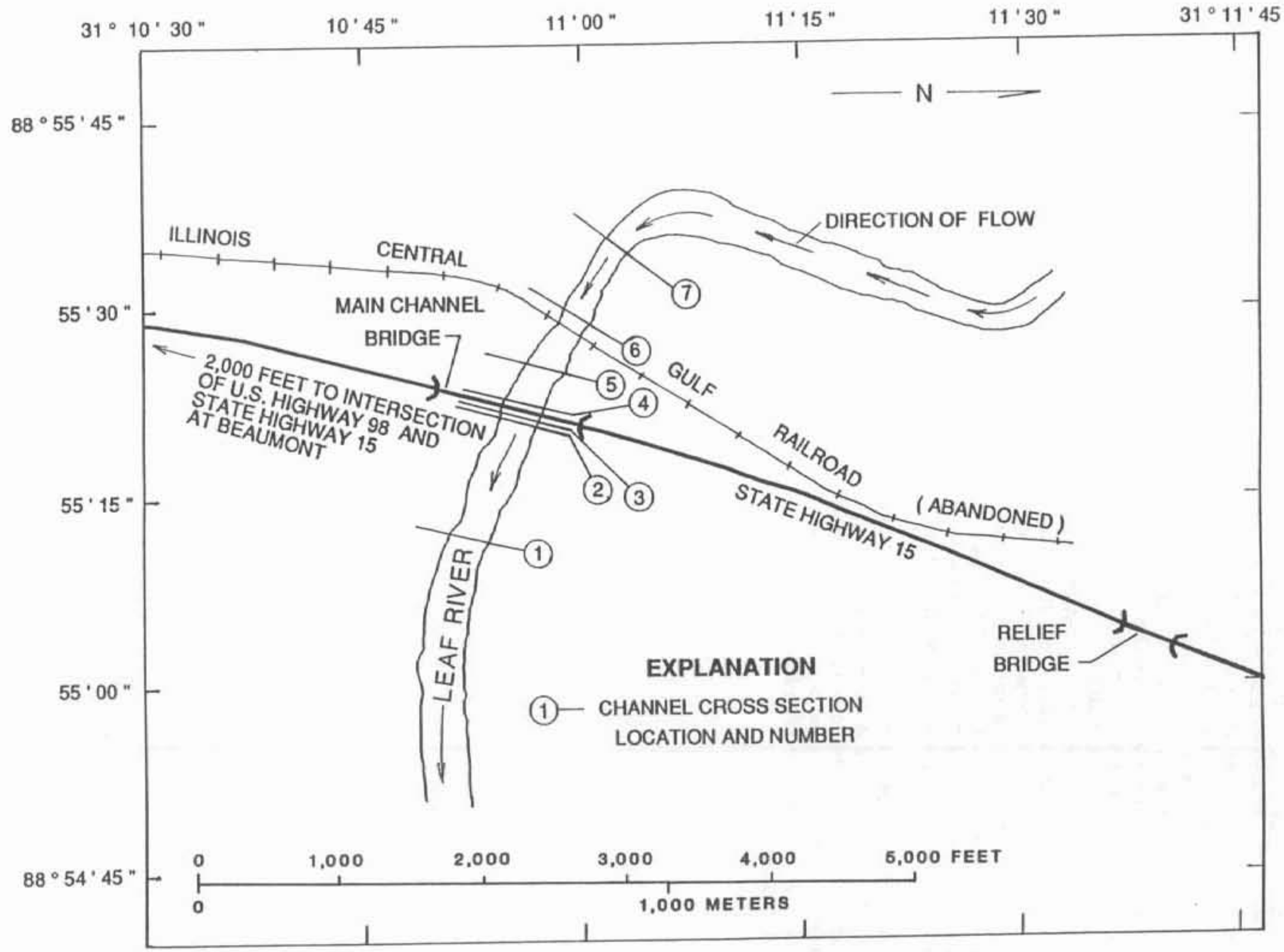

Figure 1. - - Location of Leaf River at State Highway 15 at Beaumont, Mississippi.

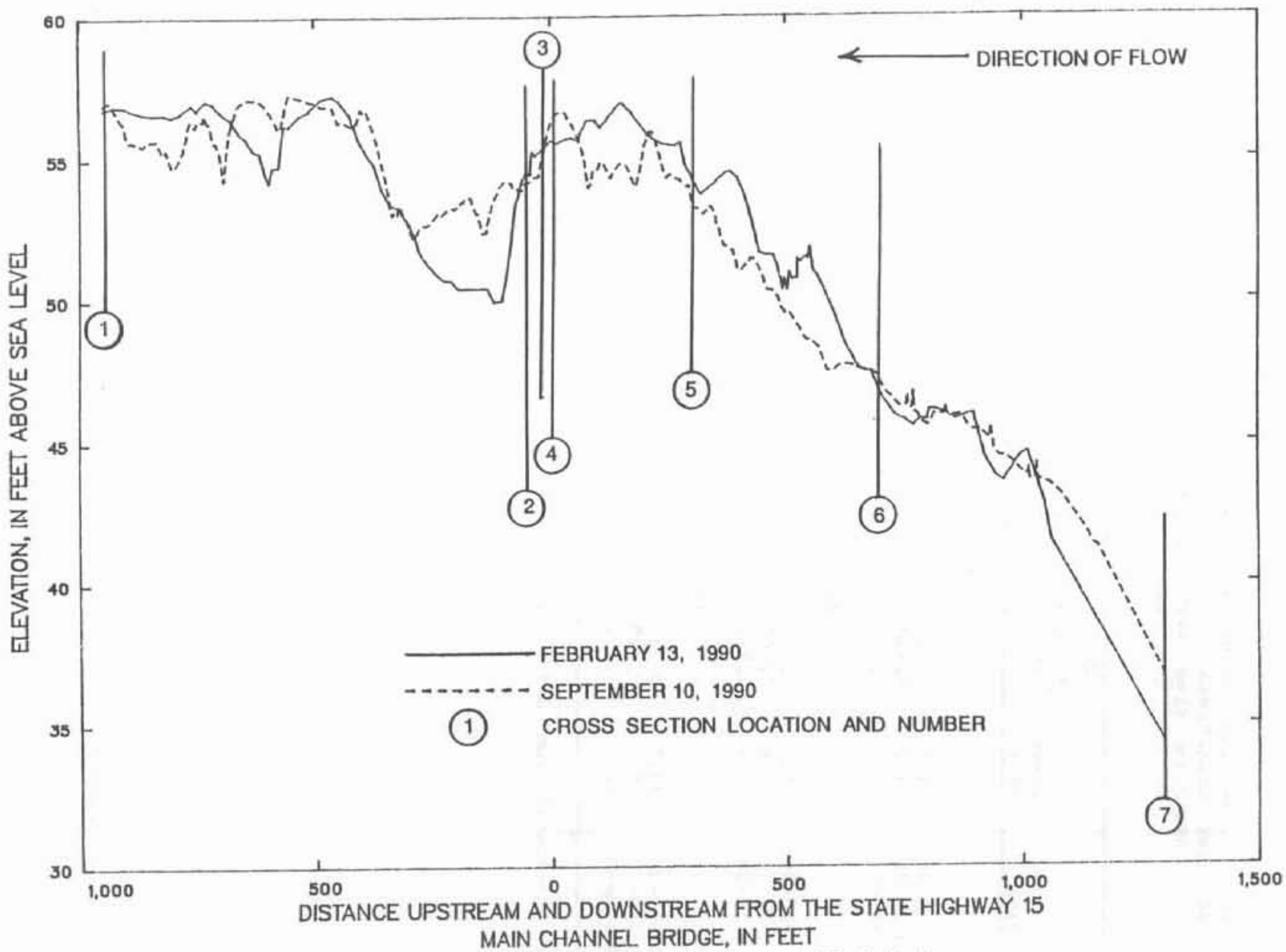

Figure 2.—Approximate thalweg profiles of Leaf River at Beaumont, Mississippi.

Table 1.--General scour at cross sections 1, 5, and 7 (about 950 feet downstream, about 300 feet upstream, and 1,300 feet upstream from main channel bridge, respectively)
[ft, feet, ft^2, square feet]

		Cross	General scour			
		section	Average bed[a]		Minimum bed	
	Stage	area	Elevation	Scour	Elevation	Scour
Date	(ft)	(ft^2)	(ft)	(ft)	(ft)	(ft)
			Cross Section 1			
02-13-90	74.3	5,350	57.3	0	54.1	0
03-27-90	64.9	2,830	55.4	1.9	52.2	1.9
09-10-90	60.1	1,110	55.8	1.5	54.0	0.1
			Cross Section 5			
02-13-90	74.5	5,610	56.1	0	53.4	0
03-27-90	64.9	2,940	54.1	2.0	52.1	1.3
09-10-90	60.1	1,770	53.4	2.7	52.2	1.2
			Cross Section 7			
02-13-90	74.7	6,380	47.5	0	34.3	0
03-27-90	65.1	3,620	46.5	1.0	34.3	0
09-10-90	60.1	2,830	43.1	4.4	36.7	-2.4

a Calculated from measured channel-bed elevations

Table 2.--Constriction scour at cross sections 2, 3, and 4 (about 50 feet downstream from, downstream side of, and upstream side of main channel bridge, respectively)
[ft, feet, ft/s, feet per second, ft^3/s, cubic feet per second]

Date	Stage at downstream side of bridge (ft)	Discharge (ft3/s)	Constriction scour (ft)			
			Average bed[a]		Minimum bed[b]	
			Elevation	Scour	Elevation	Scour
			Cross Section 2			
1937[c]	--	--	52.2	2.9	48.6	1.1
01-28-90	83.0	56,400	56.0	-0.9	51.1	-1.4
01-30-90	82.8	52,500	52.9	2.2	49.3	0.4
02-01-90	79.3	32,000	54.2	0.9	50.0	-0.3
02-13-90	74.5	18,500	55.1	0	49.7	0
02-20-90	83.8	61,000	55.5	-0.4	50.8	-1.1
03-27-90	64.9	4,810	53.9	1.2	49.0	0.7
09-10-90	60.1	1,060	53.5	1.6	49.7	0
			Cross Section 3			
1937[c]	--	--	52.2	3.2	48.6	2.4
01-28-90	83.0	56,400	54.8	0.6	50.6	0.4
01-30-90	82.8	52,500	54.0	1.4	48.4	2.6
02-01-90	79.3	32,000	54.9	0.5	50.7	0.3
02-13-90	74.5	18,500	55.4	0	51.0	0
02-20-90	83.8	61,000	53.5	1.9	49.4	1.6
02-21-90	84.2	66,100	55.1	0.3	50.6	0.4
03-27-90	64.9	4,810	54.4	1.0	50.4	0.6
09-10-90	60.1	1,060	53.4	2.0	50.2	0.8
			Cross Section 4			
1937[c]	--	--	52.2	3.7	48.6	3.3
03-23-43[d]	86.2	85,100	51.4	4.5	43.8[e]	8.1
01-28-90[d]	83.0	56,400	55.3	0.6	49.6[f]	2.3
01-28-90	83.0	56,400	56.6	-0.7	52.1[f]	1.3
01-30-90	82.8	52,500	55.7	0.2	51.9[f]	0
02-01-90	79.2	32,000	55.4	0.5	51.6[f]	0.3
02-13-90	74.5	18,500	55.9	0	51.9	0
02-20-90	83.8	61,000	55.3	0.6	50.9[f]	1.0
02-21-90[d]	84.2	66,100	52.6	3.3	45.2[f]	6.7
02-21-90	84.2	66,100	55.4	0.5	50.9[f]	1.0
03-27-90	64.9	4,810	55.8	0.1	51.1	0.8
09-10-90	60.1	1,060	54.5	1.4	50.6	1.3

a Calculated from observed channel-bed elevations.
b Scour at minimum bed may be caused by local scour processes.
c Scaled from Mississippi State Highway Dept. bridge plans, dated 1937 (prior to bridge construction).
d Sounding weight used for determining depths and velocities in discharge measurement.
e At upstream side of Pier 2.
f Near upstream side of Pier 3.

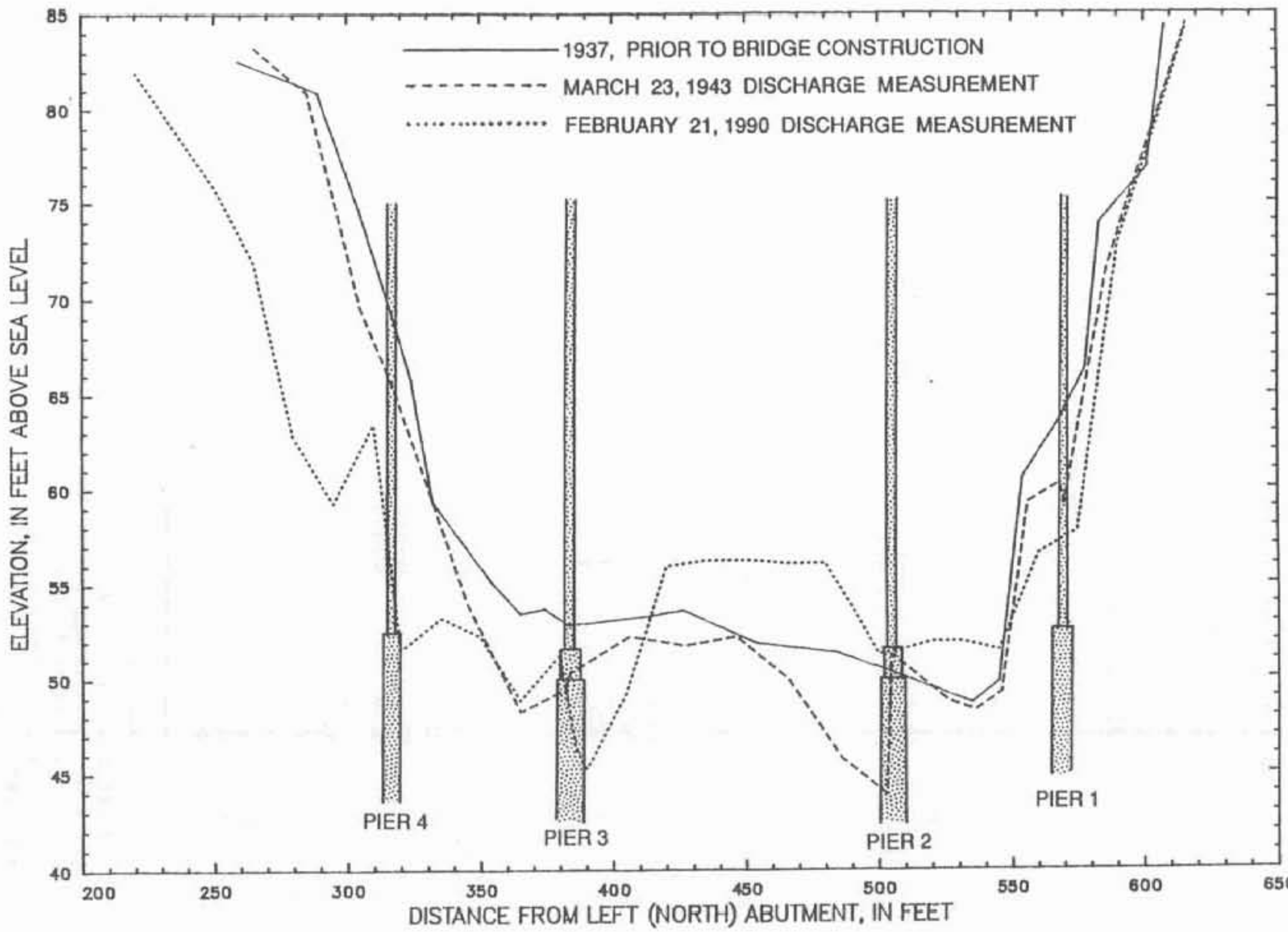

Figure 3.—–Variation of minimum bed at cross section 4, at upstream side of State Highway 15 main channel bridge at Beaumont, Mississippi.

Table 3.--Local scour estimates at main channel bridge piers

[all values in feet]

Date	Pier 1			Pier 2			Pier 3			Pier 4		
	Reference bed elevation	Pier bed elevation	Scour-hole depth	Reference bed elevation	Pier bed elevation	Scour-hole depth	Reference bed elevation	Pier bed elevation	Scour-hole depth	Reference bed elevation	Pier bed elevation	Scour-hole depth
1937[a]	--	63.8	--	--	50.3	--	--	52.8	--	--	68.6	--
03-23-43	--	59.1	--	49.7	43.8	5.9	52.0	48.2[b]	3.8	--	64.7	--
01-28-90	57.3	54.9	2.4	54.8	50.8[c]	4.0	59.9	50.6[c]	9.3[d]	60.0	52.7	7.3
01-28-90[e]	--	56.1	--	53.3	52.1	0.8	55.5	49.6	5.9[d]	55.7	53.3	2.4
01-30-90	--	55.6[c]	--	53.9	53.1	0.8	57.1	48.4[i]	8.7	55.9	53.1[c]	2.8
02-01-90	--	56.4	--	--	53.4	--	56.5	51.6	4.9	55.1	53.6	1.5
02-01-90[e]	--	56.7	--	--	52.9	--	--	52.1	--	--	53.3	--
02-13-90	60.4	56.5	3.9	55.5	52.4	3.1	56.9	53.3	3.6	57.0	52.7[c]	4.3
02-20-90	57.9	55.4	2.5	52.4	51.6	0.8	55.7	49.4[f]	6.3	54.9	51.7	3.2
02-20-90[e]	--	55.6	--	--	52.0	--	--	48.8	--	--	51.7	--
02-21-90	57.1	55.8	1.3	53.3	51.8[c]	1.5	57.4	51.1[c]	6.3	56.3	51.9	4.4
02-21-90[e]	--	56.5	--	--	51.2	--	54.4	45.2	9.2	52.7	51.5	1.2
09-10-90	--	--	--	53.4	51.5[c]	1.9	56.2	51.1[g]	5.1	56.1	51.5[h]	4.6
Maximum	60.4	63.8	3.9	55.5	53.4	5.9	59.9	53.3	9.3	60.0	68.6	7.3
Minimum	57.1	54.9	1.3	49.7	43.8	0.8	52.0	45.2	3.6	52.7	51.5	1.2

a Scaled from Mississippi State Highway Dept. bridge plans, dated 1937 (prior to bridge construction).
b About 18 ft left from upstream side of pier.
c At downstream side of pier.
d Tree caught on upstream side of pier.
e Determined using a sounding weight.
f About 9 ft left from downstream side of pier.
g On left side of pier, about 10 ft from downstream side of pier.
h About 8 ft right from downstream side of pier.
i About 14 ft left from downstream side of pier.