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SCOUR AROUND BRIDGE PIERS IN OKLAHOMA STREAMS

FINAL SUMMARY REPORT

by

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PRINCIPAL INVESTIGATOR

Report No. 89-1
Water Resources Engineering
School of Civil Engineering

Oklahoma State University
Stillwater, Oklahoma 74078
April 1989

SCOUR AND DEGRADATION AROUND BRIDGE PIERS IN OKLAHOMA STREAMS

Final Summary Report

Submitted to

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and

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Oklahoma City, Oklahoma 73102

by

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16. ABSTRACT

This study consisted of a hydrographic survey and determined maximum scour around the piers at eighteen selected bridges on the Cimarron, Arkansas, and Caney Rivers. The survey was performed soon after the 50- to 100-year-frequency flood in October, 1986. It was determined from the survey that maximum scour varied from 0.60 to 18 feet with depth of flow ranging between 0.75 to 25 feet.

The October, 1986 flood of the Cimarron River resulted in severe scour around piers of eight overflow structures of the I-35 bridge. A major portion of the flood passed through these structures, resulting in a high velocity of flow. After the flood receded, the maximum depth of scour ranged from 10 feet to 30 feet. At U.S. 75 on the Caney River, a hydraulic analysis of water surface profiles using WSPRO program was determined for 50-, 100-year, and the 1986 flood because of the old bridge and new bridge.

Because design criteria for scour depths at piers are based mostly on laboratory work and because some bridges designed according to these criteria have failed, it is recommended that this study be extended to collect field data on the maximum scour at selected bridges over a four-year period. Field data will be collected four times a year for various high and low flow conditions. Laboratory and field data are to be analyzed and used to produce design criteria so that damages to bridge piers are minimized. Further laboratory and field data will be generated for different river-bed soils (sand, silt and clay) and for varying hydraulic conditions.

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ABSTRACT

This report represents the fifth and final report in a series of technical publications covering different aspects of the 1986 Flood in the Arkansas River Basin. The main purpose of this investigation was to determine maximum scour data at different bridges in the Caney, Arkansas, Cimarron, South Canadian and Washita Rivers during high flow and low flow conditions. In addition, the backwater effect due to the October 1986 Flood is presented for U.S. 75 on the Caney River.

As part of this study, procedures were developed to determine the maximum scour and the scourhole profile using the Electronic Distance Meter and Sonar. Depth of flow varied from less than one foot to 25 feet and the scour depth from less than one foot to 18 feet. Because the river bed composition ranges between clay to coarse sand in the five rivers, maximum scour depth is affected significantly by the soil type in addition to other hydraulic variables.

Major damage occurred to overflow structures of I-35 on the Cimarron. Scour depths varied from 10 feet to 30 feet. Computer analysis of the old bridge and the new bridge at U.S. 75 on the Caney was conducted using the WSPRO program. This analysis showed that the new bridge, constructed in the 1980's, performed hydraulically better than the old bridge.

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I. INTRODUCTION

This report summarizes the findings of an investigation which was supported by the Oklahoma Department of Transportation (ODOT) and the Federal Highway Administration (FHWA) in three phases from October, 1986 through April, 1988. A major portion of the project investigation pertained to determining maximum scour after the October 1986 flood in the Cimarron, Arkansas, and Caney Rivers and analyzing the damages from the October 1986 flood in the Caney River at U.S. 75, Bartlesville, Oklahoma. This report is the fifth and final report in the series on this project.

II. SCOPE OF PROJECT

This investigation contained the following three phases:

1. The first phase consisted of collecting the data on the maximum scour on 17 bridges in the three rivers that resulted from the historical flood of October 1986.
2. The second phase analyzed the backwater effect caused by the October 1986 flood in the Caney River at U.S. 75, Bartlesville, Oklahoma. This phase also included a survey of the scourholes around overflow structures at I-35 bridge on the Cimarron River.
3. The third phase included the survey of maximum scour around bridges in the South Canadian and Washita Rivers during the summer of 1988.

All the objectives of this study were accomplished. This report summarizes the methodology and data on scourholes and the backwater effect in different phases of this investigation. Because data collected in the first phase and third phase pertain to scour depths in different rivers, these are combined in Sections III and IV. The next section includes scour depths at structures at I-35 on the Cimarron River. Then follows Section VI on backwater analysis of the 1986 flood at U.S. 75 on the Caney River. Sections VII and VIII provide the results and recommendations. The training of engineering students and publications resulting from this project are given in Sections IX and X.

II. DATA COLLECTION PROCEDURES

Hydrographic data were collected for this project on various bridge sites. A review of the construction plans for the exact pier locations, benchmark elevations, and advanced surveying equipment were used to conduct the bridge surveys and determine the maximum scour at bridge piers in the Cimarron River, Caney River, and Arkansas River.

An Electronic Distance Meter (EDM) and a sonar were used to collect data on hydraulic conditions and profiles of the scourhole at each bridge site. With this equipment, water surface elevation, channel width, and a profile of the scourholes were measured. The EDM and sonar are described below.

1. Electronic Distance Meter

The EDM is a highly advanced instrument. This instrument determines the distance by using high frequency radio waves that leave the machine, reflect from a prism held at the point where elevation is to be determined, and then return with an accurate measure of distance. This instrument greatly reduces the human error in judgment that is always possible with less sophisticated, manually operated equipment. Another feature of the EDM is its internal computer that automatically determines angle changes and horizontal, vertical, and slope distances. The EDM also determines locations of a boat from which scour depths are measured.

2. Sonar

The sonar is an instrument used in hydrographic survey to measure depths under water by emitting high frequency waves that are reflected from the bottom of the river bed back to the instrument. The depth of water at a location in the river can be measured by taking sonar readings from a boat above the point in question.

These instruments were used to determine the elevation of the water surface. The width of the ater section in the river was measured [illegible]. The river depths at different points upstream of the selected bridge pier were measured with the help of sonar and EDM. The depths from the water surface to the river bed were plotted and are presented in the next section.

IV. SCOUR DEPTH AND PROFILES

The elevations of the water surface and the river bed were measured starting from the pier in the upstream direction. A pier was selected by visual observation of the current flow. River bed elevations were taken in the upstream direction of the flow until two consecutive values were in close agreement. Elevations of pier, river bed, and water surface are shown in each profile of a scourhole.

Profiles were taken at bridge piers at Cleo Springs, Ringwood, Lacey, Dover, Cimarron City, Guthrie, I-35, Coyle, Perkins, Ripley, Cushing, Oilton-99 and Oilton-51 bridges on the Cimarron River.

Scour profiles were determined for the Sand Springs, Tulsa-33 and Ponca City bridges on the Arkansas River. Scour patterns at the Bartlesville bridge were taken on the Caney River. Measurements of scour upstream of piers were taken on the South Canadian River at I-44, U.S. 177, U.S. 75, and S.H. 2 bridges and on the Washita River at I-35, U.S. 77, and S.H. 53 bridges.

Typical profiles are shown in Figures 1 through 4. Figure 1 and 4 indicate that according to scour criteria the bridges are overdesigned. As shown in Figures 2 and 3, some bridges have deep scour and may be damaged under high flow conditions.

Scour depths were measured at thirteen bridges on the Cimarron River, three on the Arkansas River, and two on the Caney River during the 1986 flood for near high

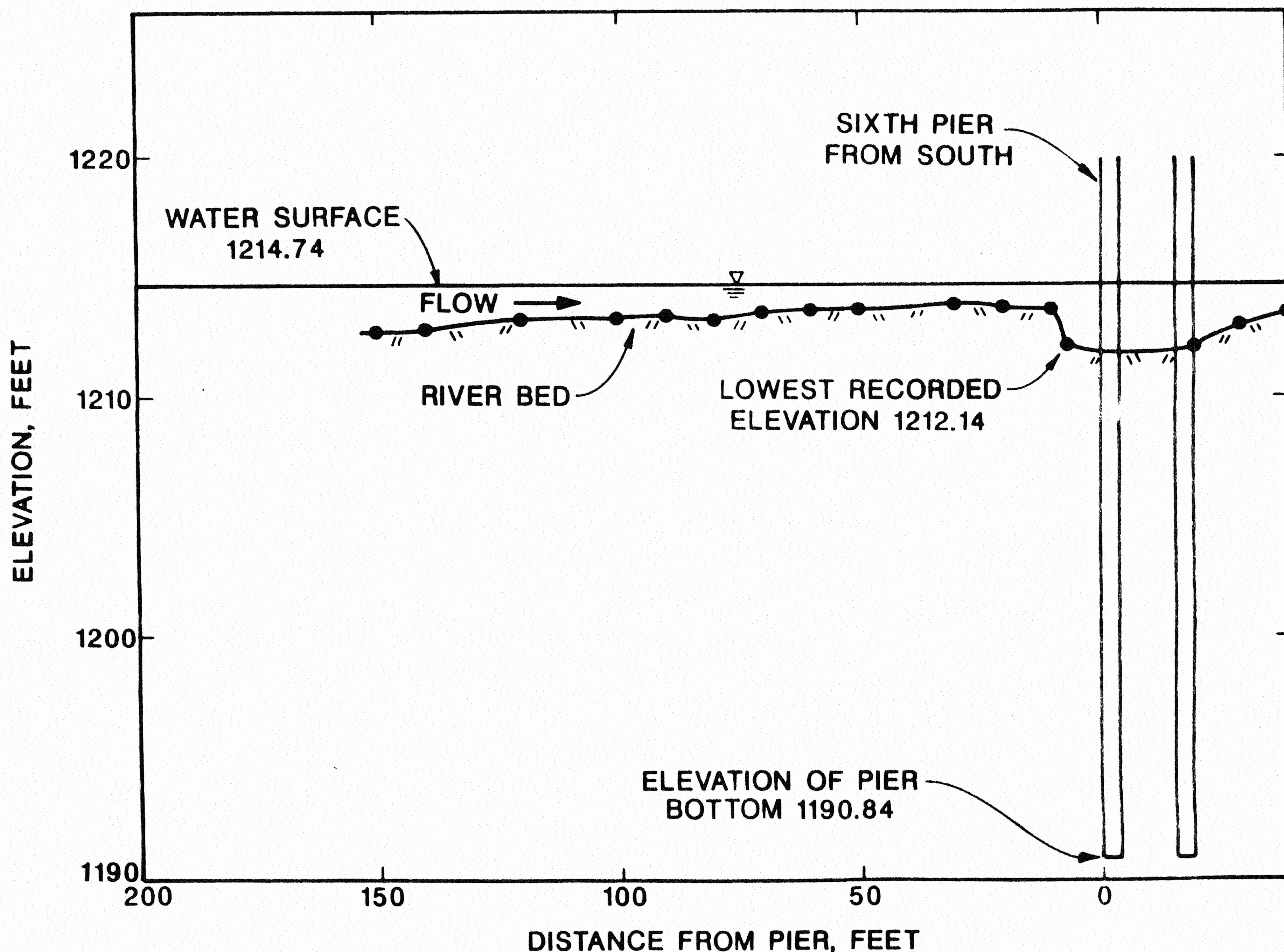

FIGURE 1. CHANNEL PROFILE AT CLEO SPRINGS, US 60, CIMARRON RIVER.

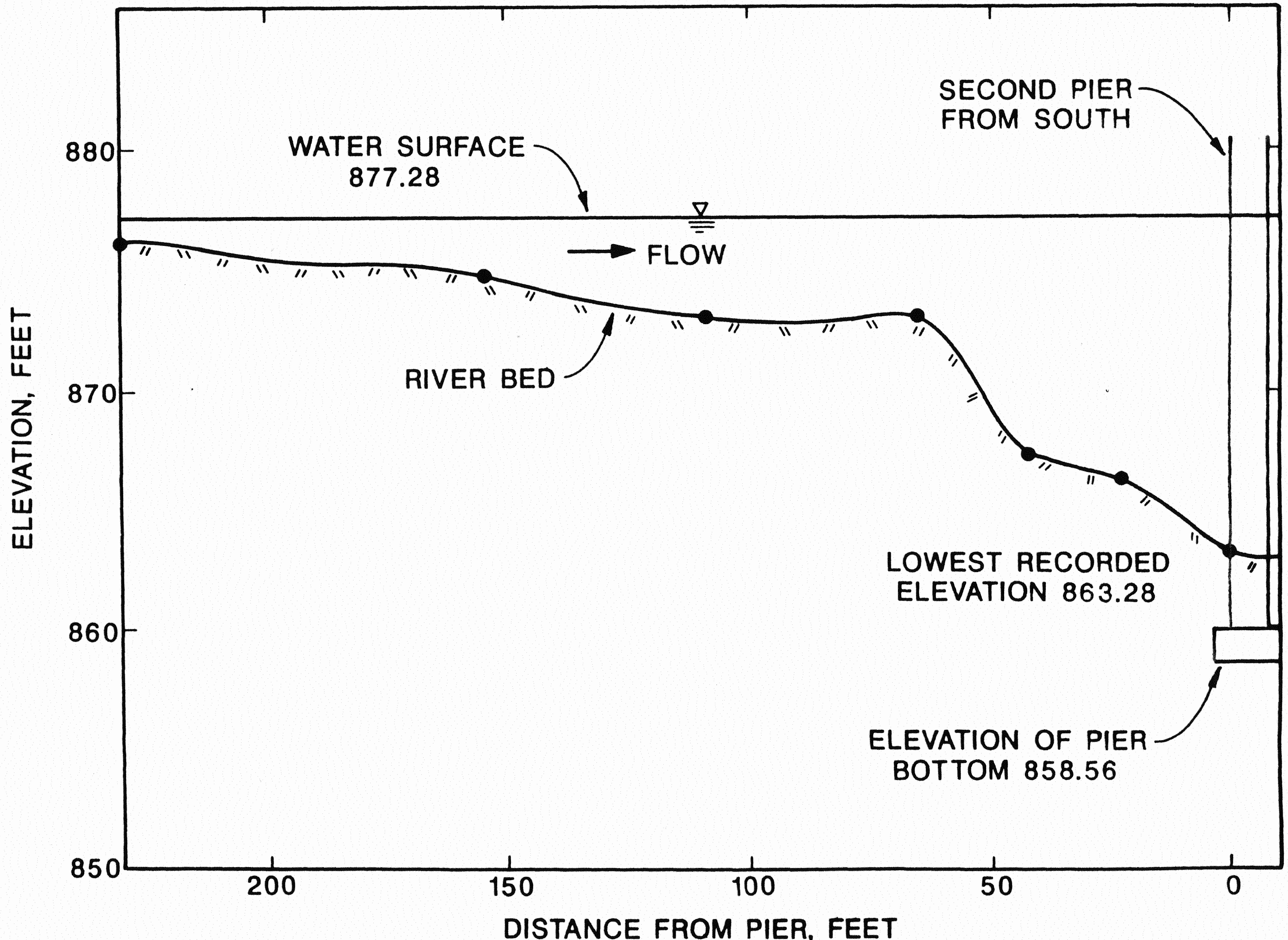

FIGURE 2. CHANNEL PROFILE AT I-35, CIMARRON RIVER.

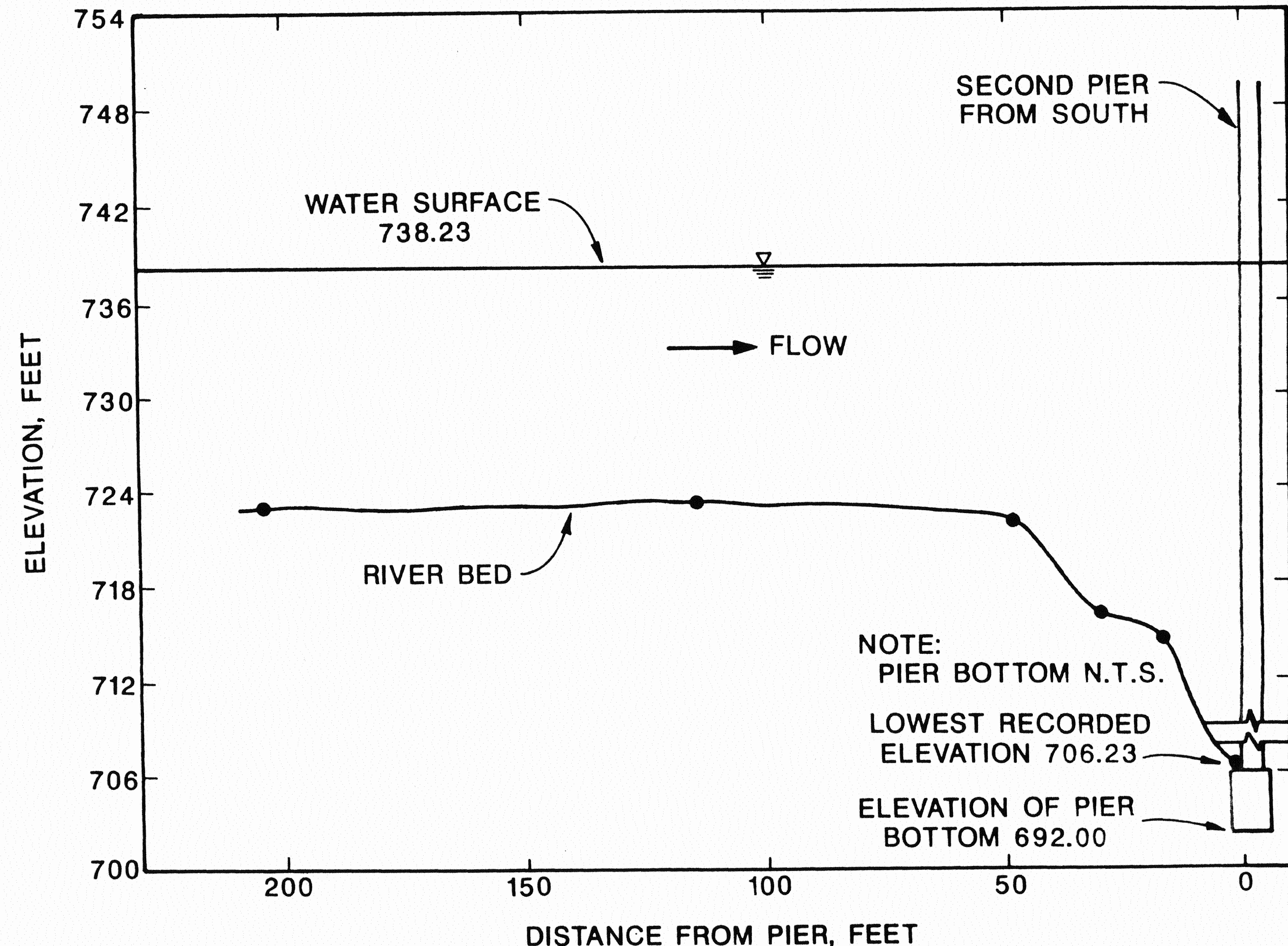

FIGURE 3. CHANNEL PROFILE AT OILTON, SH 99, CIMARRON RIVER.

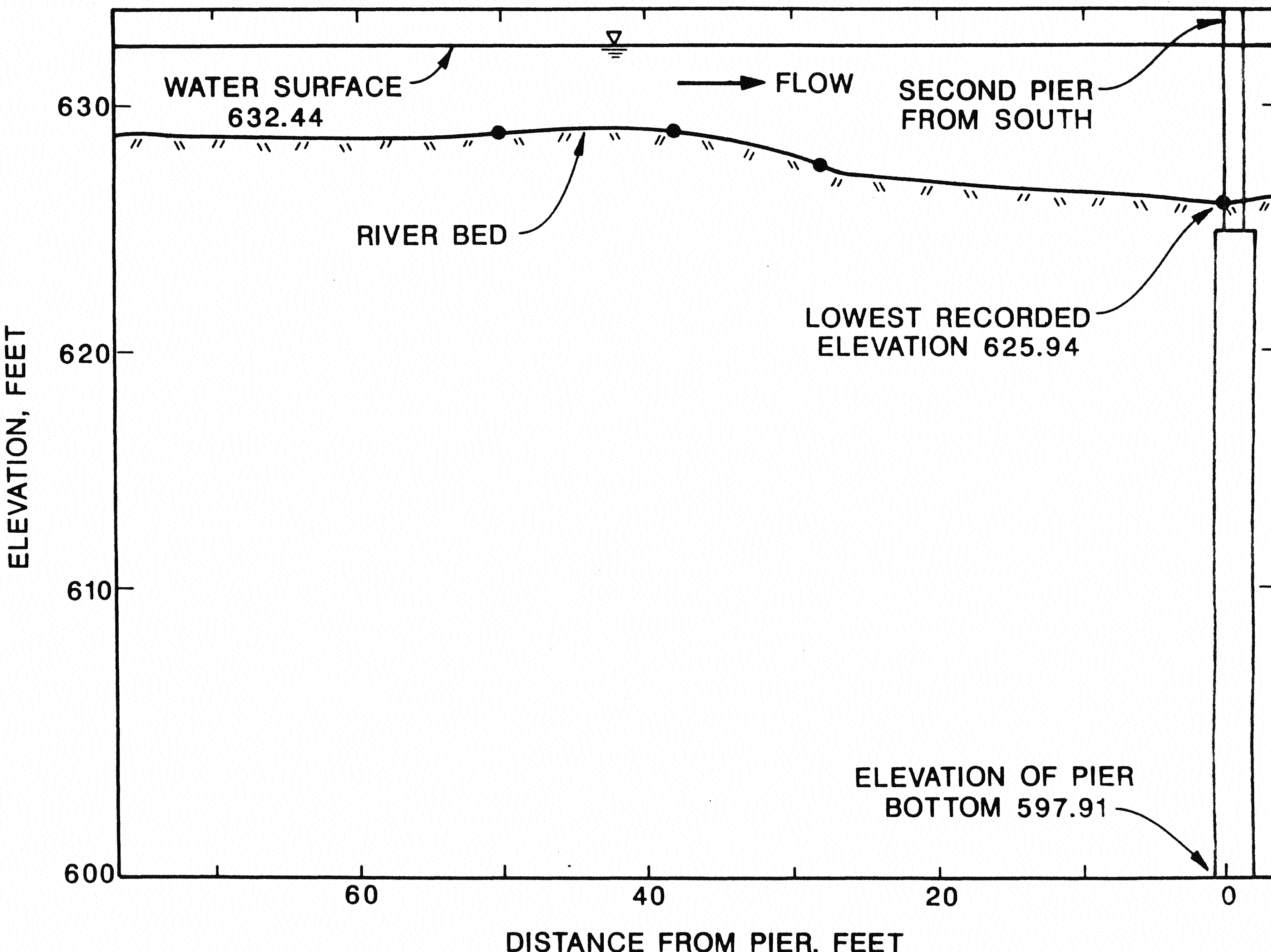

FIGURE 4. CHANNEL PROFILE AT BARTLESVILLE, US 75, CANEY RIVER.

flow conditions. Four bridges on the South Canadian River and three on the Washita River were surveyed for scour depths for low flow conditions in Summer 1988. Tables 1 and 2 present the bridge location, highway name, depth of flow, and scour depth at various piers. The depth of flow varied from 0.75 to 25 feet and the maximum scour depth varied from 0.60 to 18 feet as a result of the October 1986 flood.

A visual survey of sediments in river beds indicated that the Cimarron River has three reaches of different sediment composition. In the upper reach down to Ringwood bridge, the Cimarron is composed of boulders and sand in the river bed. From there to the Ripley bridge, the Cimarron has a wide floodplain and coarse sand in its bed. In the final reach before joining the Arkansas River, the Cimarron becomes a well-defined river. The river bed is primarily of fine sand.

In the Arkansas River, the river sediment is composed mostly of fine sand to silt, whereas the Caney River bed is composed of clay sediment. The South Canadian river bed consists of medium to fine sand and the Washita river bed is composed of silt. This is an important finding that signals the need for further investigation to determine how river sediment influences maximum scour depth.

In rivers that have wide flood plains, overflow structures are built. In Oklahoma, piles are driven to support these structures. In October 1986, maximum damage to overflow structures occurred. Aerial photographs show the elongated shape of the scourholes (see Figure 5). This phenomenon may be caused by different sediments of flood plains which are generally clayey in nature.

V. SCOUR DEPTH AT OVERFLOW STRUCTURES

This report presents data on scourholes of the eight overflow structures directly north of the I-35 bridge on the Cimarron River. These scourholes in the floodplain of the river resulted from the 1986 October flood in the river. An aerial photograph is presented in Figure 5. Eight overflow structures are labeled as Structures C, D, K, L, M, N, O, and P. Structures A and B are part of the main bridge on I-35.

TABLE I

Scour Depths At Bridge Sites During 1986 Flood (High Flow Condition)

Bridge Sites	Highway	River	Depth of flow, feet	Scour Depth feet
Cleo Springs	60	Cimarron	2.0	0.6
Ringwood	58	Cimarron	0.75	0.75
Lacey	51	Cimarron	1.7	8.9
Dover*	81	Cimarron	1.5	1.5 (4.5)**
Cimarron City	74	Cimarron	2.0	3.0
Guthrie	77	Cimarron	1.0	8.0
I-35	35	Cimarron	1.0	13.0
Coyle	33	Cimarron	1.0	16.0
Perkins	177	Cimarron	2.0	18.0
Ripley	33	Cimarron	14.0	11.0
Cushing	18	Cimarron	17.0	8.0
Oilton	99	Cimarron	15.0	17.0
Oilton	51	Cimarron	25.0	3.0
Sand Springs	97	Arkansas	15.0	9.0
Tulsa	33	Arkansas	14.0	2.0
Ponca City	60	Arkansas	4.0	3.0
Bartlesville	75	Caney	3.7	2.8
Collinsville	169	Caney	***	2.8

* Piers filled with stones
** Maximum scour at another pier
*** Piers out of water

TABLE 2

Scour Depth at Bridge Sites During Summer 1988
(Low Flow Condition)

Bridge Sites	Highway	River	Depth of flow feet	Scour Depth feet
Newcastle	I-44	South Canadian	2.2	5.9
Asher	U.S. 177	South Canadian	2.5	7.3
Calvin	U.S. 75	South Canadian	3.8	8.9
White Field	SH 2	South Canadian	4.3	9.7
Pauls Valley	I-35	Washita	3.1	8.1
Davis	U.S. 77	Washita	3.3	8.9
Gene Autry	SH 53	Washita	3.7	9.2

An Electronic Distance Meter (EDM) was used to obtain the extent and profile of each scourhole. It was placed at a point near the scourhole from which all points on the scourhole were visible. This location was referenced to a point on the bridge, such as a bridge pier. The height setting on the instrument was determined from the bridge seat elevation, the angle setting on the instrument was zero and referenced to the bridge. The perimeter was determined by taking shots at regular intervals around the scourhole and recording the angle of the shot and the horizontal and vertical distances from the instrument. The recordings were reduced to give the location and the elevation of these points on the perimeter.

All scourholes were full of water at the time of the survey, therefore, a small boat was needed for the interior shots. The water surface elevation was determined by the same method as the perimeter shots. Depth readings were taken throughout the scourholes and the location of the readings was recorded. The elevation of these points was determined by subtracting the depth from the water surface elevation.

The results are shown in Table 3. Included was a plan view and a profile for each scourhole. Each scourhole was referenced by the station numbers of the overflow structures it is between and its direction relative to the highway. The plan view indicated the approximate line of the scour profile. Scales and flow directions were indicated in each figure.

TABLE 3

Scour Depths Near Structures C, D, K Through P at I-35 Bridge on the Cimarron River

Structure	Span (feet)	Scourhole Location	Maximum Scour Depth (feet)
P	281.33	Upstream	30.0
O	281.33	Downstream	10.7
N	201.33	Upstream	15.4
M	201.33	Downstream	11.4
L	281.33	Upstream	22.7
K	281.33	Downstream	12.2
C	161.33	Upstream	10.2
D	161.33	Downstream	27.0

Figure 5 presents an aerial view of scourholes near Overflow Structures C-D, L-K, N-M and P-O. Even though the four sets of scourholes appear continuous in the aerial photograph, they sometimes contain two locations of maximum scour depths.

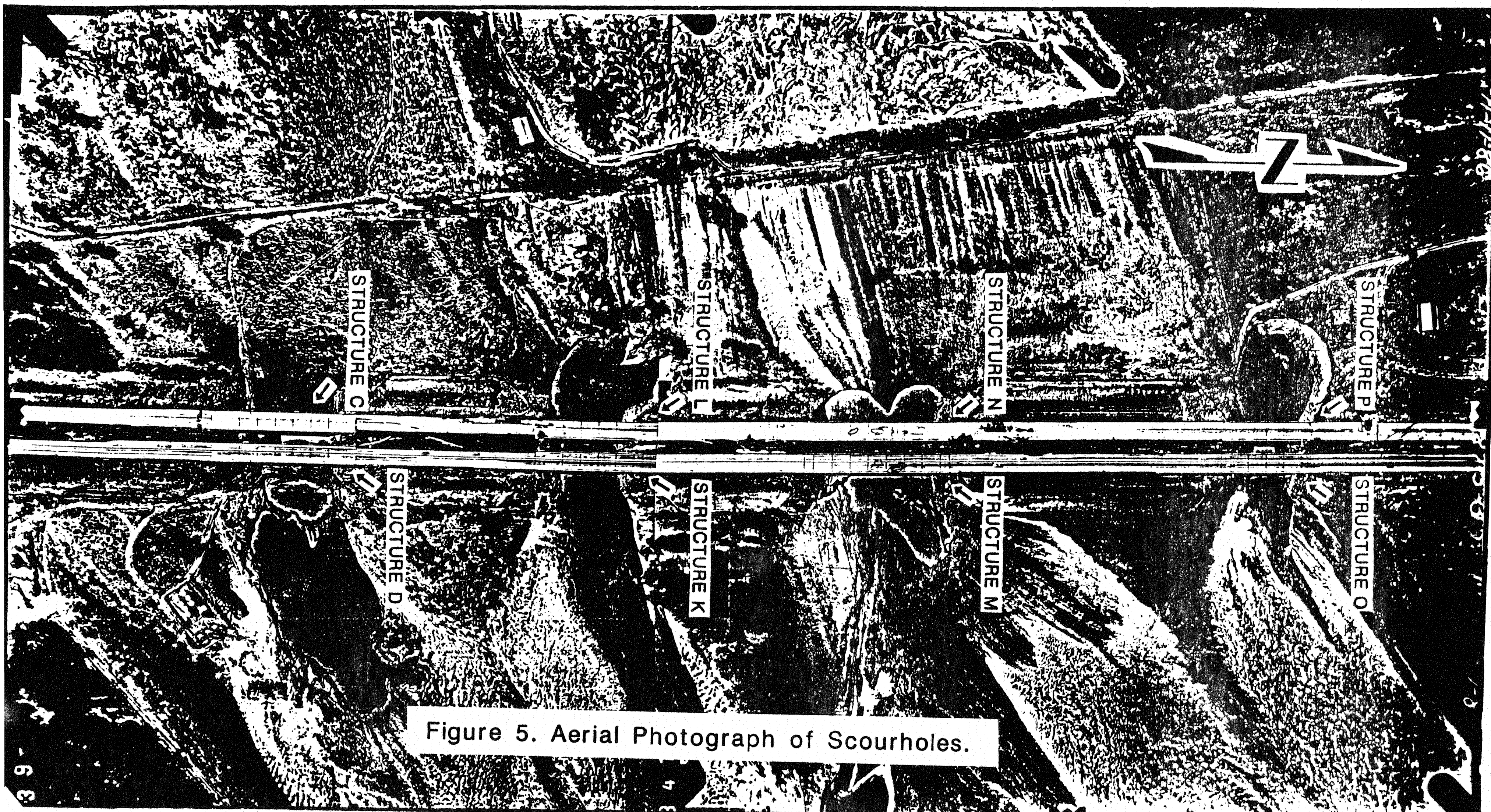

Figure 5. Aerial Photograph of Scourholes.

Table 3 gives the span of each structure. Note that Structures A and B are part of the main bridge. Also shown is the upstream or downstream location of the scourhole relative to the structure, and the maximum scour depth found after the flood receded. Most of the deep scourholes are generally located on the upstream side of the structures. A typical scourhole pattern is shown in Figures 6 through 9 at Overflow Structures P and D. The maximum scour depths near these structures were measured as 27 and 30 feet, respectively. The values of maximum scour depth ranged from 10 to 30 feet near various overflow structures.

VI. BACKWATER ANALYSIS AT U.S. 75

A large storm known as Hurricane Paine produced a rainfall of 20 to 30 inches over the Arkansas River Basin. This large rainfall over a six-day period (September 29 through October 4, 1986) resulted in extensive flooding in the Cimarron, Arkansas, and Caney Rivers. Because of this extremely heavy rainfall that exceeded 20 inches, the local residents questioned the adequacy of the bridges that were built in 1984. The ODOT initiated this phase of the research investigation as an objective study of the hydrologic and hydraulic design of the bridges and the policies and procedures used in the design. This study analyzes various hydraulic conditions for the old bridge and new bridge and determines the impact of Hulah and Copan Lakes on the water surface profile at U.S. 75 bridge near Bartlesville.

Four hydraulic conditions are analyzed to predict water surface profiles using the WSPRO computer model. The WSPRO model has been developed by the Federal Highway Administration. The four cases include Case I - Profiles for new bridge (50-year, 100-year and 1986 Flood), Case II - Profiles for old bridge (50-year, 100-year and 1986 Flood), Case III - Profiles without embankment (50-year, 100-year, and 1986 Flood), and Case IV - Profiles for the old bridge without Hulah and Copan Lakes.

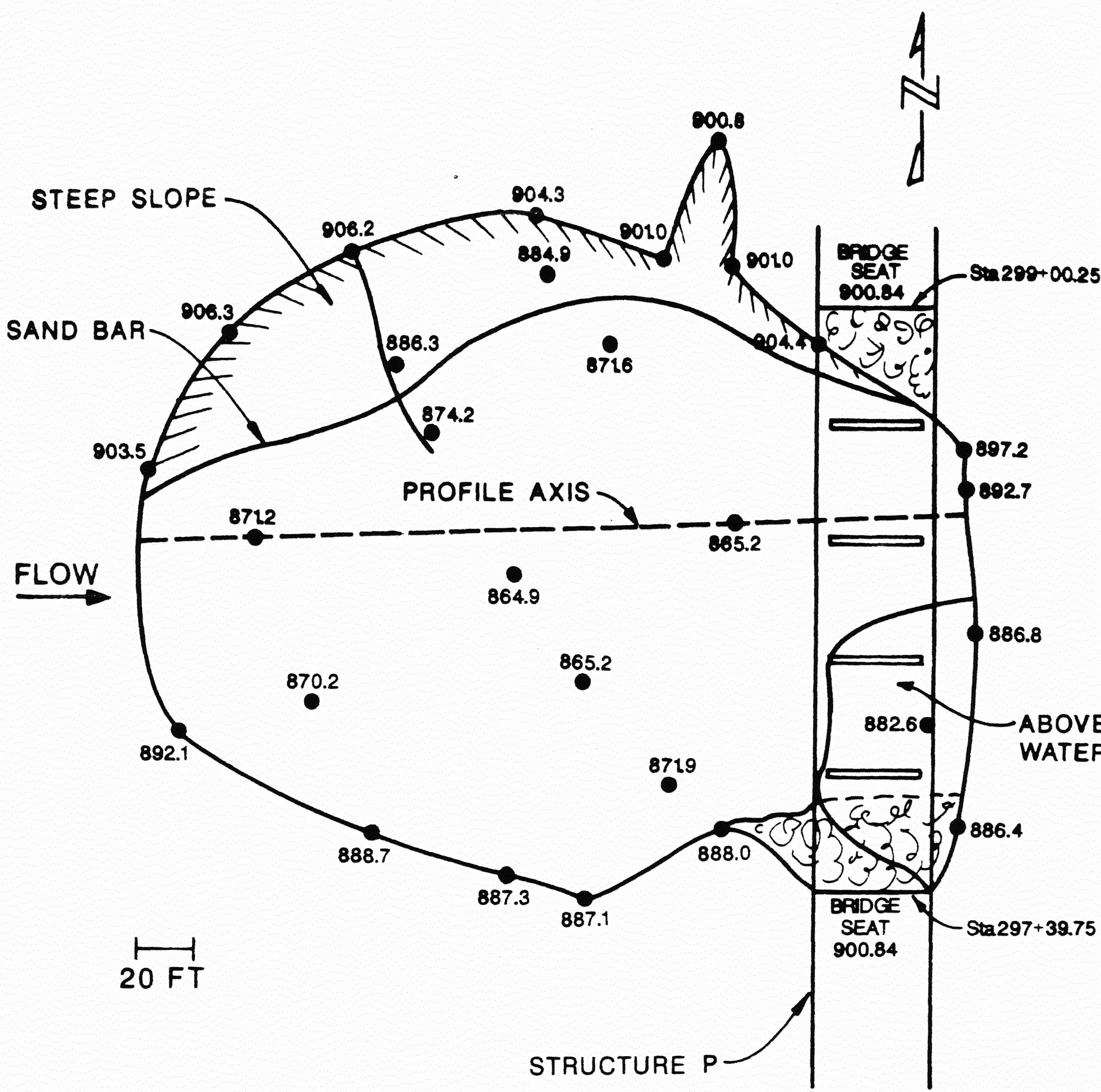

Figure 6. Location of Scour Hole Upstream of Structure P.

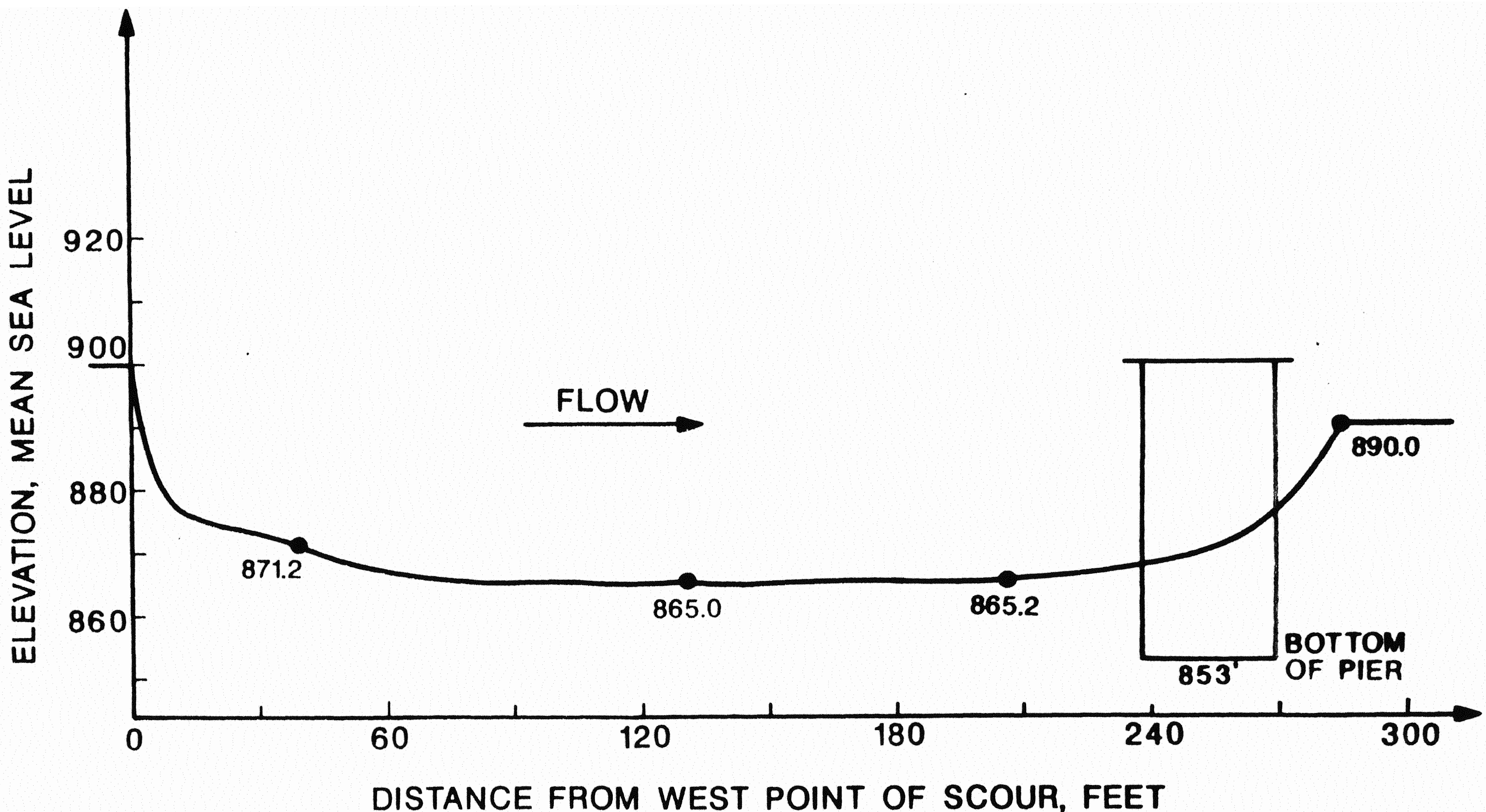

Figure 7. Profile of Scour Hole Upstream of Structure P.

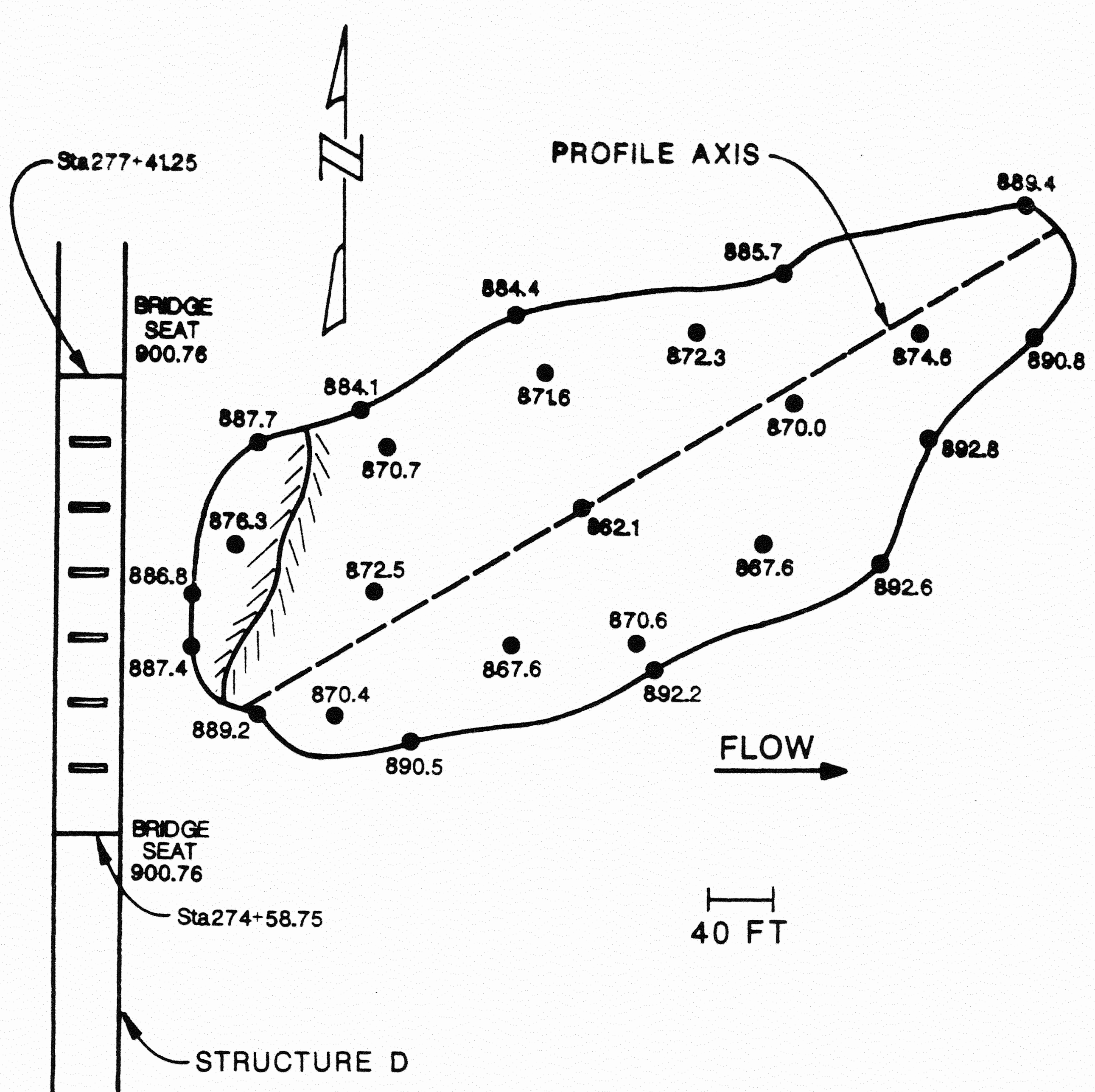

Figure 8. Location of Scour Hole Downstream of Structure D.

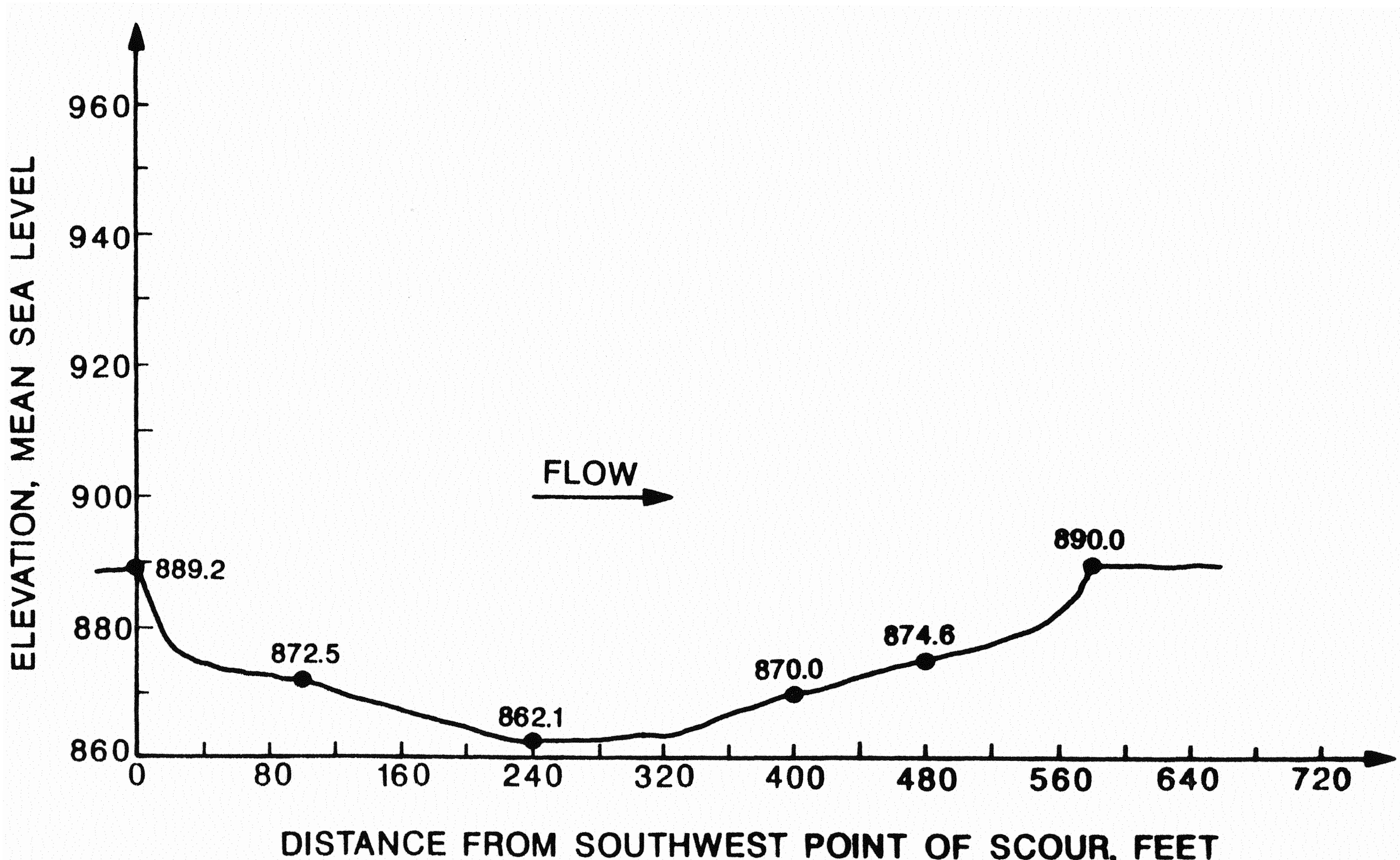

Figure 9. Profile of Scour Hole Downstream of Structure D.

To determine the backwater effects of the new bridge and the old bridge, water surface elevations between Case I and III and Case II and III are subtracted one bridge length upstream. In addition, water surface elevations between Case I and Case IV are subtracted to determine how the old bridge, built in 1930 without Hulah and Copan Lakes, compares with the new bridge in terms of hydraulic efficiency.

Procedures and policies on bridge design for primary highways (such as U.S.75) are developed by FHWA and adopted by the ODOT as presented in Appendix J (Tyagi, 1988 c). Computer analysis indicates that the construction of the new bridge causes a backwater effect on the range of 1 to 2 feet and maximum velocity between 6 to 8 feet per second for 50-year and 100-year floods (see Table 4). Tables 3 through 8 summarize these results (Tyagi, 1988 b). The computer analysis further indicates that construction of the new bridge has resulted in lowering the water surface elevation by 2 to 3 feet as compared to the old bridge without Hulah and Copan Lakes. At the time of construction of the old bridge in the 1930s the two lakes did not exist. In addition, a review of policies and procedures of the ODOT and the new bridge design on U.S 75 of the Caney River shows that the design is within the guidelines.

The FHWA and ODOT policies indicate that a bridge on a primary highway should be designed for a 50-year flood and be checked for a 100-year flood. It is not cost-effective to design the bridge for higher frequency floods because of the life of a reinforced concrete bridge (30 to 50 years). To overdesign the bridge is a waste of state funds and taxpayers' money. The new bridge was designed for 50-year and checked for 100-year floods.

The siltation in the 1986 Flood occurred on the upstream side of the new bridge in the floodplain. However, limited loss of soil would occur within 150 to 180 feet upstream of the overflow structures. Depending on the right-of-way within U.S. 75 slight damage because of soil loss would be experienced upstream and downstream of the two overflow structures. A jet is issued out of the overflow structure along the county road (Tyagi, 1988 c). Thus, scour damage is mostly limited to the road in the immediate vicinity of the highway and two county roads.

TABLE 4

COMPARISON OF VELOCITIES AND BACKWATER EFFECT BETWEEN OLD BRIDGE AND NEW BRIDGE

	Old Bridge	New Bridge
50-year flood discharge (Q_{50})	91,011 cfs	42,800 cfs
100-year flood discharge (Q_{100})	115,697 cfs	51,400 cfs
50-year velocity at Main Structure (V_{50})	6.16 fps	5.10 fps
50-year velocity at Overflow Structure 1 (V_{50})	5.63 fps	5.98 fps
50-year velocity at Overflow Structure 2 (V_{50})	5.43 fps	5.54 fps
100-year velocity at Main Structure (V_{100})	7.11 fps	5.82 fps
100-year velocity at Overflow Structure 1 (V_{100})	6.63 fps	6.85 fps
100-year velocity at Overflow Structure 2 (V_{100})	6.41 fps	6.37 fps
Backwater effect for 50-year flood	1.22 ft	1.28 ft
Backwater effect for 100-year flood	1.55 ft	1.56 ft

The backwater effect upstream of the exit section of the bridges is computed for a 500-year flood or a discharge of 108,000 cfs. Using the WSPRO model, this effect due to new and old bridge options is determined extending to 5.55 and 3.66 miles upstream from U.S. 75.

The residents have built dikes along the Caney River in the floodplains. Once the flood water passes over dikes from the main river, dikes obstruct drainage from floodplain to the main river. Water ponds in the flood plain until it is drained by overflow structures.

The concept of floodplain utilization is that it can be used for agriculture but it is expected that a high flood of 50 to 100 to 500 year frequency will cause flooding in the floodplain. The 1986 flood is analyzed by the Corps of Engineers (1987) as a 500-year flood. Obviously, crop damages are expected to occur, but these are not caused by the construction of the new bridge and U.S. 75.

VII. RESULTS

This investigation produced the following results:

1. Hydrographic surveys of scour measurements at bridge piers during high (1986 Flood) and low (summer) flows indicate that the depth of flow varies from less than one foot to 25 feet and that the corresponding scour depth ranges between less than one foot and 18 feet. Scour surveys were conducted in the Caney, Arkansas, Cimarron, South Canadian, and Washita rivers.
2. At the time of the October 1986 Flood, surveys of severe scour damage at overflow structures on I-35 on the Cimarron River showed that scour depths varied within a range of 10 to 30 feet.
3. Computer analyses of the old bridge constructed in the 1930's and the new bridge constructed in the 1980s indicate that the new bridge is hydraulically more efficient than the old bridge without Hula and Copan Lakes.

VIII. RECOMMENDATIONS

1. Perform hydrographic surveys to determine the maximum scour depth at piers two to three times a year for a period of four years. Bridge sites on Oklahoma rivers should be selected. Develop an equation based on field data for predicting scour depth and compare with available laboratory data from literature.
2. From the files of ODOT and USGS, collect historical data of scour depth, depth of flow, and discharge on selected bridge sites. Also, obtain stratigraphic data from ODOT files on layers of sand, silt, and shale in the river bed.
3. Collect soil samples from different sites to classify river-bed sediments and correlate with scour depths.
4. Use EDM and sonar to obtain scour profile, maximum scour depth and degradation of river bed near selected depths.
5. Explore automation of recorders that can digitize collected field data in computer-readable format. Develop software to plot this data on the IBM-AT computer.
6. Select a package, such as, LOTUS 1-2-3, DBASEIII, SAS, and others, for analyzing, reducing and plotting the field data collected in Oklahoma streams.
7. Perform laboratory experiments using sediments existing in the field at selected bridge sites, and measure the maximum scour around cylindrical piles in flood plains overflow structures and streamlined piers in main stream bridge sections. Laboratory scour experiments use both cohensionless (sandy and silty) and cohesive (clayey) soils.

IX. TRAINING

This project supported and trained a maximum of 14 engineering students during the field work to collect scour data in various Oklahoma streams.

X. PUBLICATIONS

The following technical publications and presentations resulted from this project:

1. Tyagi, A. K., "Scour Around Bridge Piers in Oklahoma Streams," Report No. 87-1, Water Resources Engineering, Oklahoma State University, Stillwater, Oklahoma, pp. 24, March 1987.

2. Tyagi, A. K., "Scour Around Bridge Piers of Overflow Structures at I-35 Bridge on the Cimarron River," Report No. 88-1, Water Resources Engineering, Oklahoma State University, Stillwater, Oklahoma, pp. 21, April 1, 1988 a.

3. Tyagi, A. K. "Analysis of October 1986 Flood in Caney River at U.S. 75, Bartlesville, Oklahoma," Volume I, Report No. 88-2, Water Resources Engineering, Oklahoma State University, Stillwater, Oklahoma, pp. 36, September, 1988 b.

4. Tyagi, A. K. "Analysis of October 1986 Flood in Caney River at U.S. 75, Bartlesville, Oklahoma," Volume II, Report No. 88-3, Water Resources Engineering, Oklahoma State University, Stillwater, Oklahoma, pp. 136, September, 1988 c.

5. Tyagi, A. K., "Impact of 1986 Flood on Oklahoma Bridges in Cimarron River," Am. Soc. Civil Engrs., Oklahoma City, November, 1987 (Invited).

6. Tyagi, A. K., "Scour Survey in Cimarron, Arkansas, and Caney Rivers," Oklahoma Department of Transportation, Oklahoma City, Januray, 1988.

7. Tyagi, A. K., "Scour from 1986 Flood in Oklahoma Streams," In: Regional Conference, Federal Highway Administration, Kansas City, Kansas, March, 1989 (Invited).

8. Tyagi, A. K., "Effect of Flood of 1986 in the Arkansas and Caney Rivers," Am. Soc. Civil Engrs., Tulsa, Oklahoma, September, 1989 (Invited).

9. Tyagi, A. K., "Oklahoma Flood of 1986," Transportation Research Board January, 1990 (Invited).