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16. Abstract

The computerized system for the organization, analysis, and display of field collected scour data is described. This system will enhance the current manual procedure of accomplishing these tasks. The system accepts input from the user, and based on user specification, allows the data to be organized and viewed in a variety of formats. These include cross sections from scour measurements at selected locations upstream or downstream of the bridge, longitudinal profiles through a selected pier, or the temporal history of maximum scour activity within a given specified area near the bridge. The data may be viewed in tabular as well as graphical formats. In addition, the available scour data in four bridge sites were analyzed and used to develop regression equations which relate long-term channel degradation at these bridge sites to flow and geometric variables. These equations were incorporated into the computer system such that the user may input desired hypothetical discharges and stages and the system will compute the resulting long-term scour. This hypothetical value is then added to the scour activity graphs so the hypothetical bottom elevation can be compared to the existing bottom and critical pier elevations. Various digital hydrographic survey equipment systems were also investigated and recommendations are made with regard to possible future purchases.

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AUTOMATION OF SCOUR ANALYSIS AT LOUISIANA BRIDGE SITES

FINAL REPORT

by

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RESEARCH REPORT NO. 217

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LOUISIANA DEPARTMENT OF TRANSPORTATION AND DEVELOPMENT
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in Cooperation with
U.S. Department of Transportation
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DECEMBER, 1988

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ABSTRACT

The computerized system for the organization, analysis, and display of field-collected scour data is described. This system will enhance the current manual procedure of accomplishing these tasks. The system accepts input from the user, and based on user specification, allows the data to be organized and viewed in a variety of formats. These include cross sections from scour measurements at selected locations upstream or downstream of the bridge, longitudinal profiles through a selected pier, or the temporal history of maximum scour activity within a given specified area near the bridge. The data may be viewed in tabular as well as graphical formats. In addition, the available scour data for four bridge sites were analyzed and used to develop regression equations which relate long-term channel degradation at these bridge sites to flow and geometric variables. These equations were incorporated into the computer system such that the user may input desired hypothetical discharges and stages and the system will compute the resulting long-term scour. This hypothetical value is then added to the scour activity graphs so that the hypothetical bottom elevation can be compared to the existing bottom and critical pier elevations. Various digital hydrographic survey equipment systems were also investigated and recommendations are made with regard to possible future purchases.

IMPLEMENTATION STATEMENT

The computer software developed in this study has been turned over to LDOTD. LSU personnel have assisted the department in installation and bebugging of the software. We are aware of no current problems with the system. When the system was completed, the data base consisted of the hydrographic surveys for the four bridges discussed in the report. The scour prediction equations for these bridges have also been calibrated and programmed into the system. Thus, the system is fully operational for these four bridge sites.

However, if the full capability of the SAMS is to be realized, a major commitment must be made by LDOTD during the implementation phase and thereafter. This effort will involve inputting existing data for the numerous bridges currently monitored as well as an extensive data collection program. Sufficient data for calibration of the scour prediction equations are currently available for a maximum of 12 bridge sites (Table 1). If other bridges are to be evaluated, data will have to be collected over a period of time at these sites. These data include discharge and scour observations taken over concurrent periods. It is also important that new hydrographic surveys for all bridges be religiously input into the system as they become available.

It has been estimated by LDOTD personnel that a period of approximately 2 years would be required to make the system fully operational using currently available manpower. During this period, hydrologic data could be collected concurrently with the scour surveys at all bridges which will eventually be part of the system. The data requirements and reporting procedures necessary for the calibration of the scour prediction equations are given in the recommendations section of this report and in Appendix I. It is recommended that a minimum of 10 sets of scour and hydrologic data be used in the calibration procedure. Therefore, the monitoring schedule could be adjusted accordingly.

An alternative procedure would be to purchase the mobile pier mounted digital survey system discussed in this report. With this equipment, real time scour data could be collected during each event at the subject bridges. In this way, sufficient data would be collected in a short time for equation calibration. This procedure would have the added advantage of using real time scour data, thus the equation could be calibrated to maximum observed scour rather than low water observations as is now done. The authors feel that this procedure (and equipment purchase) should be considered very seriously by the department. It would result in the most efficient and reliable scour monitoring system currently possible.

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LIST OF SYMBOLS

V	average approach velocity (ft/sec)
Y	approach flow depth (ft)
d_s	scour depth (ft)
D	pier diameter or projected pier width perpendicular to main flow direction (ft)
L	pier length (ft)
g	acceleration of gravity (ft^2/sec^2)
α	angle of incoming flow (degrees)
F	$V/\sqrt{gY}$: flow Froude number
F_p	$V/\sqrt{gD}$: pier Froude number
R_e	VY/μ: Reynolds number
R_p	VD/μ: pier Reynolds number
V_c	critical velocity: velocity at incipient sediment motion
F_c	critical Froude number: Froude number at incipient sediment motion

METRIC (SI*) CONVERSION FACTORS

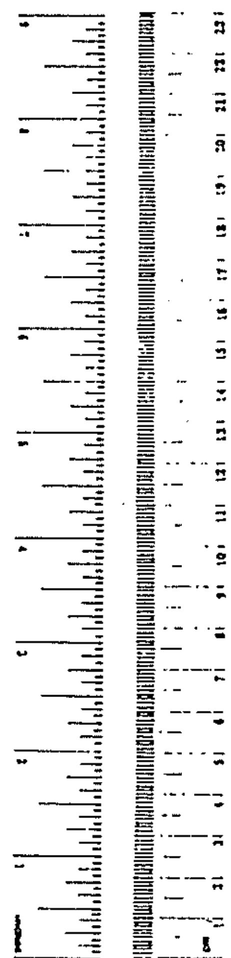
APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

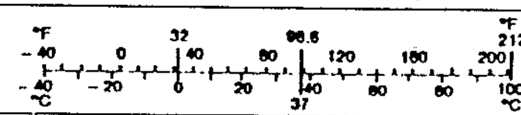
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

INTRODUCTION

GENERAL

The scouring of the streambed around the piers supporting highway bridges has come to be recognized as a major problem facing the highway engineer. The failure of bridges due to pier scour poses a serious threat to highway safety as well as to the property and commerce of the affected area. It is becoming increasingly obvious that the possibility of scour must be taken into account in the design phase of bridge construction. However, it is also important that bridges which face possible scour situations be monitored during their lifetimes. In order to gain maximum efficiency, the monitoring program should be carefully constructed to collect the most important data in the most valuable format. Much data will be collected during the monitoring phase. These data must be organized and analyzed in the most efficient manner possible. The organization and analysis of field-collected scour data are the topics with which this project is concerned.

PRESENT SCOUR MONITORING PROCEDURE

Presently, the Louisiana Department of Transportation and Development (LDOTD) is monitoring about 80 bridges to detect possible danger of failure due to pier scour. These bridges are surveyed at intervals of six months, one year or two years depending upon the perceived severity of the potential scour problem at each bridge. The scour surveys are taken with an analog fathometer by taking cross sections at selected intervals upstream and downstram of the bridge. These intervals, like the survey time intervals, are bridge specific. The fathometer charts are marked by the survey crew at locations corresponding to the locations of specific piers of the bridge under investigation.

Occasionally, locations between piers will also be marked. The chart is then delivered to the LDOTD Location and Survey Section where the bottom elevations at the marked locations are read and entered on the scour survey sheets (Fig. 1). These sheets, therefore, only report elevation at locations upstream or downstream of the bridge corresponding to particular pier locations. There are not sufficient data reported to plot an entire cross section of the channel.

The scour survey sheet is then forwarded to the district office, the LDOTD Bridge Maintenance Section and the LDOTD Hydraulics Section. Personnel within the hydraulics section evaluate the survey sheet and compare it with past surveys to determine the relative severity of the scour situation. If the situation is deemed to be critical, then the bridge design section is alerted so that corrective measures may be planned and executed. The entire monitoring process is illustrated on the flow chart shown on Figure 2. It is also noted that presently, neither sediment nor discharge data are taken by LDOTD.

The present monitoring procedure can be very time-consuming. The purpose of this project was to design a computerized system to store, analyze, and plot historical survey data. In addition, given certain variables by the user, possible future trends in the scour profiles can also be estimated and plotted for comparison with existing data.

LITERATURE REVIEW

The engineering literature contains numerous references with regard to scour analysis. These references report the results of various studies involving laboratory flume data, hydrodynamic analyses and, in a few cases, field studies. Empirical scour analyses usually take the approach represented

BRIDGE NO. 0470500001 DISTRICT: 62 ROUTE: LA. 10 PARISH: WASHINGTON

NAME PEARL RIVER BRIDGE @ BOGALUSA DATE OF LAST SURVEY: 11-19-76

CONTROL SEC. 47-05 STRUCTURE TYPE: 60 DATE OF CURRENT SURVEY: 11-18-77

BENT	PIER NO.	RANGE	ORIG. BOTTOM ELEV.	1ST. SURVEY BOTTOM ELEV.	EXIST BOTTOM ELEV.	TOTAL SCOUR (-) OR BUILDUP (+)	CRITICAL ELEV.	CHANGE FROM LAST SURVEY		BOTTOM OF PIER ELEV.
								SCOUR	BUILDUP	
	2	2+00 UP		57.4	65.5	+8.1		N/A		30.1
	3	2+00 UP		42.4	54.5	+12.1			1.3	30.1
35		2+00 UP		56.8	49.5	- 7.3			4.0	25.0
	2	1+00 UP		57.8	55.0	-2.8			1.5	30.1
	3	1+00 UP		50.8	47.3	- 3.5			1.3	30.1
35		1+00 UP		49.6	45.5	-4.1			1.5	25.0
	1	0+20 UP	47.0		56.2	+ 9.2			8.7	31.3
	2	0+20 UP	44.5		52.5	+8.0			6.6	30.1
	3	0+20 UP	48.2		53.2	+5.0			7.4	30.1
35		0+20 UP	68.4		60.1	-8.3			3.2	25.0
	1	0+20 DOWN	47.0		42.5	-4.5			2.1	31.3
	2	0+20 DOWN	44.5		48.7	+4.2			1.2	30.1
	3	0+20 DOWN	48.2		46.4	-1.8			0.4	30.1
33		1+00 DOWN		69.0	65.5	-3.5		N/A		30.5

Figure 1. Typical Scour Survey Sheet

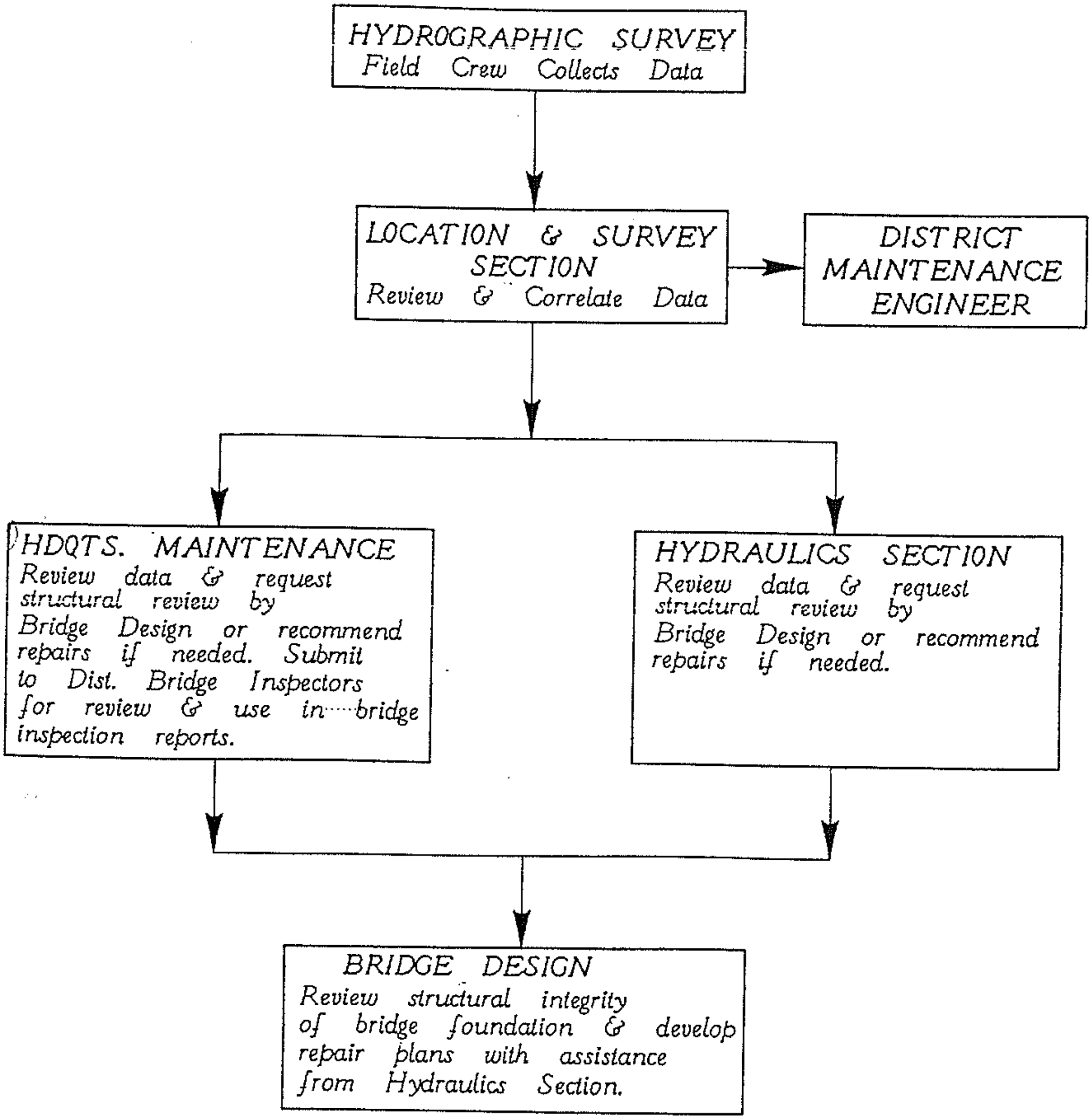


Figure 2. Flow Chart of Current Monitoring Procedure

by many laboratory flume studies and the few existing field studies. This approach involves an attempt to empirically relate observed scour to variables representing hydraulic, geometric, and geotechnical parameters. Regression techniques are used to derive empirical equations which describe the observed trends in the dependent variable in terms of independent variables.

Many relationships of this kind have been developed by past researchers using laboratory flume data. However, there is a fundamental difference between the scour predicted by these equations and the data reported by LADOTD. Scour of stream beds can be broken into three general categories: general scour, contraction scour, and local scour. General scour results from the natural tendency of streams to modify their channels. Several changes in course and a general wearing down of the stream bed take place over the lifetimes of most rivers. Contraction scour results when constrictions are placed in a channel which result in a localized increase in flow velocity. This type of scour occurs not only in the immediate vicinity of the constriction, but also along a relatively long reach of the river. Local scour is the result of an obstruction placed in the flow path. The obstruction causes localized changes in the hydraulics of the flow, resulting in an increase in the scouring rate.

Most researchers have realized that while general scour may be an ongoing process through all flow regimes, constriction and local scour are most evident during periods of high flow. Thus, laboratory flume studies have generally been concerned with the prediction of the maximum scour which would develop under a given set of flow and geometric conditions. In this context, scour is measured as the maximum degradation of the experimental channel bed from its position prior to the beginning of the experiment.

Unfortunately, this is not the scour data which is being reported by the LADOTD survey sheets. The only data available are the differences in channel elevation at selected locations between the current survey and the previous survey, which may have been taken six months or one year earlier. Thus, these scour observations encompass all three types of scour. In addition, the maximum scour which may have developed during any flood periods was undoubtedly offset somewhat by filling in of the scour hole during the low flow periods. Other factors are also present in the field scour situation which cannot be duplicated in flume studies. Field scour development may be complicated by the presence of debris which often accompanies flood flows and may obstruct the piers, changes in channel geometry which may direct flow away from the pier and the presence of a downstream control which may affect the hydraulics near the pier. Another important factor in scour development is the presence or absence of a sediment load in the incoming flow. If no sediment discharge is present, this "clear water" scour can be much more significant than the case when sediment is already present (9). However, clear water conditions may only exist at discharges which are too small to affect incipient sediment motion. All of these factors cannot be accounted for in laboratory flume studies. Thus the exact equations reported in the literature cannot be used in this study.

The purpose of this study was not to derive new equations for predicting scour. Rather, it was merely to provide an objective, analytical procedure to be used by LADOTD personnel to accomplish what they are currently doing visually and subjectively. Namely, this is to analyze the observed bottom profiles to determine if the scour situation at a particular bridge is likely to get better or worse. Thus, this study was dedicated to the search for a general trend analysis equation which would be calibrated to each existing bridge.

Nevertheless, the basic principles imbued in the relationships given in the literature may be useful for this purpose. Perhaps the earliest study of bridge scour was performed by Laursen (1), who related scour depth to the depth of flow and pier diameter. Following up, Shen (2) related the equilibrium scour depth to the pier Reynolds number and the pier Froude number. In these dimensionless parameters, the pier diameter is used in lieu of the flow depth. Thus,

$$R_p = \frac{VD}{\mu} \tag{1}$$

$$F_p = \frac{V}{\sqrt{gD}} \tag{2}$$

where:

R_p = pier Reynolds number

F_p = pier Froude number

V = average approach velocity of the flow (ft/sec)

D = diameter of the pier (ft)

μ = kinematic viscosity of water

Hopkins (3) modified the Shen formulas to include flow depth as an independent variable. More recently, Subhash (4) related scour depth to flow depth, pier diameter and critical Froude number. The critical Froude number is defined as the Froude number of the flow at incipient sediment motion. Raudkivi (5) found that maximum scour depends on pier size, sediment type and gradation, flow depth, and pier alignment.

The common principle throughout all of these results is that scoür is directly related to variables representing the hydraulic and geometric factors of the particular situation. Chang (6) made a study of field scour observations at seven locations in Louisiana. Chang defined scour as the degradation of the channel bottom at a particular location below the general trend exhibited by the cross section. Using this definition of scour, and under generally low flow hydrologic conditions, he determined that the most accurate of the prediction equations given in the literature was the Hopkins modification of the Shen formula:

$$\frac{d_s}{D} = 3.4 \, (F_p)^{2/3} \, (\frac{Y}{D})^{1/3} \qquad (3)$$

where:

d_s = scour depth (ft)

D = pier diameter (ft)

Y = mean flow depth (ft)

It is noted that this formula contains variables which only can be thought of as arising from application of the energy principle. This confirms the intuitively appealing concept that scour should be well-related to the energy of the incoming flow. This concept will form the basis of the derivation of the formulas to be used in this study.

OBJECTIVES

The objectives of the study described in this report were:

1. To develop a computer graphics and data management system to store, organize, and visually display current and historic scour data.
2. To develop and test a methodology of empirical scour analysis using currently available data.
3. To analyze and compare commercially available scour measurement and processing equipment and make recommendations to LADOTD with regard to possible purchases of digital equipment.
4. To make recommendations to LADOTD regarding additional data requirements and/or changes in the current data collection procedure.

SCOPE

The scope of this report will encompass the empirical scour analysis, development of the computer data management and graphical packages, and the analysis of the current scour measurement and reporting procedure. The scour analysis portion will consist of a discussion of the development of a relationship between observed scour measurements and parameters which describe the flow and geometric situation of the bridge. Only empirical (regression) procedures will be discussed; i.e., no hydrodynamic analyses were attempted.

The computer data management and graphics system will be discussed and user information will be attached. Currently available scour measurement devices will be compared and recommendations will be made in regard to possible purchases. In addition, recommendations regarding changes in the data collection procedures and additional data to be collected will be made.

METHOD OF PROCEDURE

The discussion of the methodology of this study will be done in three sections. Section 1 will describe the development of the empirical scour model, Section 2 will deal with the computer packages and Section 3 will compare existing survey equipment.

EMPIRICAL TREND ANALYSIS

As stated above, the scour analysis dealt with only one type of empirical scour evaluation technique. This was due to the severe limitations on the available data. The only useful data which are currently reported by LADOTD are the scour observations themselves. In addition, the as-built drawings and original core boring logs were also available for the bridges to be analyzed. Due to the dearth of available data, locations had to be chosen so that other necessary data would be available from alternate sources. Primarily, this restricted the analyses to those bridges at which U.S. Geological Survey stream gages are located. At these locations, both discharge records and stream cross sections were available. With these data, empirical relationships involving scour, discharge, and geometric bridge variables could be tested.

There are twelve bridges which are currently in the monitoring program and at which stream gages are located. A list of these bridges is given in Table 1. Thus in effect, the scour, discharge and cross section data at these twelve locations comprised the available data base for the scour analysis study.

The scour surveys are currently taken from a boat using a Raytheon fathometer. Continuous readings are taken but only bottom elevations at selected distances upstream and downstream of particular piers are reported. These

TABLE 1

BRIDGES FOR WHICH HYDROLOGIC DATA EXISTS

Bridge (Route)		Survey Record	Gage Record
U.S. 190	Amite R. nr. Denham Spgs.	1976-	1940-
La. 42	Amite R. at Port Vincent		*1983-
U.S. 190	Bayou Nezpique nr. Basile		1938-
La. 392	Bayou Toro nr. Toledo Bend		+1976-
U.S. 190	Calcasieu R. nr. Kinder		1961-
La. 26	Calcasieu R. nr. Oberlin	1979-	1938-
La. 2	Ouachita R. at Sterlington		**1979-
La. 10	Pearl R. nr. Bogalusa	1974-	1938-
I 59	Pearl R. at Pearl R.		+1975-
La. 173	Twelvemile Bayou nr. Dixie		1942-
La. 26	Whiskey Chitto Creek nr. Oberlin	1977-	1944-
La. 90	Wax Lake Outlet at Calumet		+1976-

*Gage operated by COE before 1983

+Stage recordings only

**Crest stage indicator gage

locations are not always consistent from one survey to the next. A typical pattern of reported survey locations is shown in Figure 3.

The data for the bridges shown in Table 1 were examined and several were selected for further analysis. Selection was based on the completeness and consistency of both discharge and scour data. Reasons for rejecting bridges included: backwater conditions, tidal influences, limited or insufficient scour data, and unavailability of flow records. The purpose of this study was only to develop and test a methodology of empirical trend analysis, not to analyze every bridge in the data base. Thus it was only necessary to select a few bridges to develop and test the equations. The chosen procedure was to attempt to identify the general form of a formula which would adequately describe observed Louisiana scour data. Of course, the equation would have to be calibrated for each individual bridge to which it would be applied.

Ultimately, three bridge locations were chosen for the initial development and testing of the necessary equation. A fourth bridge was later chosen on which to test the derived equation form. If a single form of an equation for scour analysis could be identified which would accurately describe the data for all four of these bridges, then it might also be accurate in other cases throughout the state. The four bridges selected were Whisky Chitto Creek (LA 26), Pearl River Bridge (LA 10), Amite River Bridges (US 190) and New Calcasieu River Bridge (LA 26). These bridges are located in various regions of the state and thus represent varying hydrologic and geotechnical conditions.

The scour reporting sheets for these bridges were obtained from LADOTD. The discharge records for the stream gages at these locations were obtained from the USGS. The channel cross sections which are periodically taken by the

Typical Plan View of a Bridge

Showing Where Readings are Taken

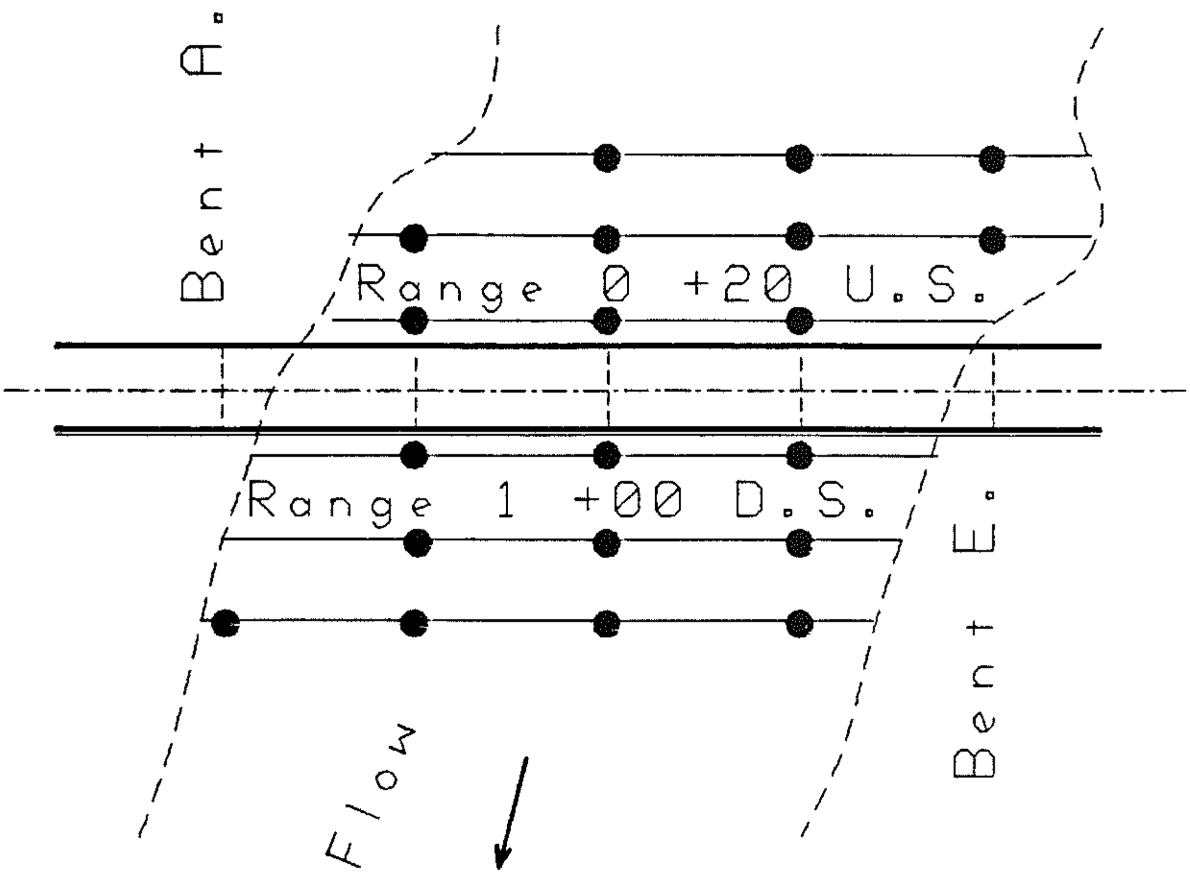


Fig. 3 Typical Plan View of a Survey.

survey at these gage locations were also available. These sections normally extend only from the edge of the water at the time the surveys were taken. However, by superimposing the surveys, composite cross sections could be constructed. Thus hydraulic properties such as Froude number, Reynolds number, depth, velocity, etc. could be calculated using these composite cross sections and the available discharge records.

As previously discussed, the exact forms of the equations given in the literature could not be used here because of the differences in the way scour was measured and defined. The major problem was that laboratory flume studies are concerned with the analysis of the maximum scour which develops during given flow conditions for a particular bridge geometry. The field observations which were available for this study do not represent maximum scour measurements under flood conditions. Instead, they represent the total degradation of the channel bottom from all causes since the time of the last survey. Still, this degradation must have been caused by some combination of hydraulic conditions, along with other factors such as pier geometry and sediment parameters.

Using all the available data, various relationships involving scour and hydraulic and bridge properties were tested on the three original bridges. The hydraulic parameters (such as those listed above) were calculated using flows taken in various ways relative to the date of the scour surveys. The average discharge between scour surveys, the maximum discharge between surveys, and the peak discharge of the flood which occurred closest to the survey date were all tested to determine which gave the best relationship to the observed scour data. Preliminary analyses determined that the best correlation existed between the measured scour and the hydraulic properties of the flood discharge closest to the date of the scour survey. Table 2 gives a

TABLE 2

PRELIMINARY FLOW ANALYSIS

Survey Date	Closest Flood Date	Scour	Max Flow Between Surveys (cfs)	Avg Flow Between Surveys (cfs)	Closest Flood to Survey (cfs)
		Pearl River - LA 10			
06-12-80	05-20-80	-8.2	107000	22785	56500
10-19-78	06-09-78	-6.6	37300	10853	11200
11-19-76	05-19-76	-6.6	56500	9572	16400
08-08-74	06-13-74	-5.6	99000	20886	11200
07-28-83	07-01-83	-5.5	68200	23252	24800
06-08-84	05-14-84	-3.8	41300	11893	17200
02-12-75	01-27-75	-2.9	47400	12040	36500
08-16-79	07-17-79	-1.9	129000	19157	18300
06-24-82	04-29-82	-1.7	34400	5351	22400
04-14-83	04-08-83	-1.6	114000	20154	114000
05-28-81	05-23-81	-1.3	12000	5832	9300
		Amite River - US 190			
03-30-83	03-27-83	-3.1	46800	2553	11400
04-27-77	04-23-77	-3.0	110000	9843	110000
01-15-81	12-12-80	-2.3	68600	2851	11300
05-25-78	05-19-78	-2.2	31300	3103	7770
05-14-76	05-11-76	-1.8	29900	2697	25600
03-24-77	03-06-77	-1.7	14100	1404	14100
11-14-77	11-04-77	-1.0	110000	3049	4640

comparison of the scour and the flows calculated by the three methods given above for two of the bridges analyzed. From analysis of these data, it appeared that the scour data were better correlated to the flood flows nearer the survey date than the other two discharge values. This would imply that there is very little sediment movement in these streams during low water conditions. Therefore, when testing the various equations, flood discharges were invariably used.

The observed scour was taken as the difference between the current survey elevation and the previous survey elevation at the locations at which the scour problem was determined to exist for a particular bridge. Scour has been defined in this manner by LADOTD personnel since the inception of the manual phase of their monitoring program. Thus, the purpose of this study was to derive an analytical procedure for determining if trends are present in these data and, if so, to relate these trends to measurable flow and geometric parameters. Thus the determination of the location of the "scour hole" was the first step in the analysis. This was accomplished by examining the survey data to determine the location of the most significant scour activity in relation to critical pier parameters. In some instances the location of the scour problem extended across more than one pier or more than one location (upstream or downstream) relative to the piers.

With the scour determined in this way, the energy-based equations (as previously mentioned) were tested using the regression procedures in the Statistical Analysis System (SAS) package commercially available from the SAS Institute of Raleigh, NC. Various forms of equations given in the literature were tested as well as new equations developed in this study. The data base used in these analyses is given in Table 3. The hydraulic parameters were calculated by using the USGS cross sections taken at the closest time after

TABLE 3

DATA USED IN REGRESSION

La 26 Bridge on the Whisky Chitto Creek

Flood Date	Total Flow	Channel Flow	Flow Depth	Stage	Local Bottom	Avg. Vel.	Local Vel.	F	α	Scour	Pier	D	ds/D	Re Pier
03-04-77	3030	2933	10.88	57.75	47.6	2.124	2.028	0.1135	0.17	-4.3	B 23 16U	1.17	-3.675	204,183
02-14-78	1560	1448	7.60	54.35	44.8	1.887	2.198	0.1207	0.17	-2.0	B 24 16U	1.17	-1.709	181,456
01-08-79	2540	2123	10.68	56.85	42.5	1.801	2.193	0.0971	0.17	-3.4	B 26 16U	1.17	-2.906	173,150
09-22-79	19,300	1,7216	20.39	67.55	46.5	2.262	2.310	0.0883	0.17	-2.4	B 23 16U	1.17	-2.051	217,458<->
07-05-81	1600	1600	6.90	54.15	45.0	1.722	2.079	0.1155	0.17	-3.4	B 23 16U	1.17	-2.906	165,577
06-10-84	3540	3370	10.65	58.86	47.3	1.448	1.530	0.0782	0.17	-0.7	B 24 16U	1.17	-0.598	139,232<*>

La 10 Bridge on the Pearl River

Flood Date	Total Flow	Channel Flow	Flow Depth	Stage	Local Bottom	Avg. Vel	Local Vel.	F	α	Scour	Pier	D	ds/D	Re Pier
06-13-74	11,200	7,885	19.6	70.39	46.2	1.027	1.182	0.0409	0.05	-5.6	P 3 20U	6.1	-0.917	515,561
01-27-75	36,500	20,112	23.7	74.48	52.1	1.948	1.875	0.0705	0.02	-2.9	P 1 20U	5.0	-0.527	880,200<->
05-19-76	16,400	8,790	18.3	72.40	45.9	0.869	1.351	0.0315	0.0	-6.6	P 2 20U	30.0	-0.220	2,142,918
06-09-78	11,200	8,288	12.4	65.78	46.6	2.596	3.473	0.1299	0.0	-6.6	P 3 20U	5.0	-1.320	1,066,759
07-17-79	18,300	9,260	16.8	72.97	45.9	1.410	1.938	0.0606	0.0	-1.9	P 3 20D	5.0	-0.380	579,314
05-20-80	56,500	27,629	21.5	75.41	37.7	2.956	4.299	0.1123	0.0	-8.2	P 3 20D	5.0	-1.640	1,214,278
05-23-81	9,300	6,659	15.3	69.95	45.4	1.287	1.764	0.0580	0.0	-1.3	P 2 20U	30.0	-0.043	3,173,103
04-29-82	22,400	11,491	18.8	73.50	38.3	1.554	2.360	0.0631	0.0	-1.7	P 3 20D	5.0	-0.340	638,334
04-08-83	114,000	50,388	24.7	77.78	36.7	4.822	6.769	0.1710	0.0	-1.6	P 3 20D	5.0	-0.320	1,981,216<->
07-01-83	24,800	12,673	20.6	73.63	47.6	1.685	1.969	0.0654	0.0	-5.5	P 2 20U	30.0	-0.183	4,153,076
05-14-84	17,200	9,305	19.5	72.60	41.7	1.362	1.851	0.0543	0.0	-3.8	P 2 20D	30.0	-0.127	3,356,460

US 190 Bridge the Amite River

Flood Date	Total Flow	Channel Flow	Flow Depth	Stage	Local Bottom	Avg. Vel	Local Vel.	F	α	Scour	Pier	D	ds/D	Re Pier
03-06-77	14,100	11,463	17.67	26.26	8.1	1.619	1.649	0.0679	0.09	-1.7	P 1 C.L	4.50	-0.378	598,600
04-23-77	110,000	71,940	21.89	41.08	4.8	2.546	3.565	0.0959	0.00	-3.0	B 7 47D	4.50	-0.667	941,350
11-04-77	4,640	4,640	14.73	19.30	7.1	1.493	1.317	0.0684	0.05	-1.0	P 1 C.L	8.01	-0.125	982,511
05-19-78	7,770	7,009	18.55	23.39	4.9	1.542	1.539	0.0631	0.09	-2.2	P 1 C.L	9.10	-0.242	1,153,481
12-12-80	11,300	9,673	20.28	24.49	5.9	1.455	1.373	0.0569	0.09	-2.3	P 1 47D	9.10	-0.253	1,088,046<+>
03-27-83	11,400	9,633	20.81	24.92	2.8	1.332	1.388	0.0515	0.07	-3.1	P 1 47D	8.56	-0.362	936,888

NOTE: Assuming one pier and no influence by the others.

Convention: <-> = Outlier; <*> = Data are unreliable; <+> = Scour measured from 05-78 to 01-81.
Units: feet/seconds/degrees.

these floods. These surveys were generally taken within a few days or weeks of the flood periods and were thus considered to be the best representation of the true cross sections during the actual flood.

These cross sections were of course very irregular. Therefore, algorithms had to be developed to approximate the necessary hydraulic parameters. The cross-sectional areas were calculated by dividing the section into small triangles and rectangles and then summing the areas of these figures. The mean channel bottom elevation was approximated by choosing representative points from the channel bottom at equidistant points. The elevations of these points were then averaged to obtain the mean bottom elevation. The average flow depth for any flood event was then obtained by merely subtracting the mean bottom elevation from the flood stage.

Of course, during periods of high discharge, the main channel will sometimes overflow. Thus the total cross sectional area as calculated above will include the area in the channel overbanks. The flow in the overbanks might exhibit lower velocities than those in the main channel. However, after discussion with LADOTD hydraulics personnel, it was determined to use the average velocity of the entire cross section in the calculations. Velocities were calculated by determining the fraction of the total discharge which occupied the main channel and dividing this discharge by the area of the main channel. Thus the total discharge was apportioned between the channel and overbanks according to their respective areas. With the mean channel depths and velocities determined in this manner, the Froude numbers and Reynolds numbers were calculated by the formulas given previously. Where local velocities were necessary, the approximation given in Chang (6) was used:

$$V_{local} = V\ (Y_{local}/Y)^{2/3} \qquad (4)$$

In cases of divided flow, the discharge in the part of the cross-sectional area where the piers of interest were located was apportioned according to the area of this part of the section as described above.

SCOUR ANALYSIS AND MANAGEMENT SYSTEM (SAMS)

As previously stated, the scour surveys are currently done by fathometer. The strip chart from the fathometer is then read in the office and the sounding data entered on the scour survey sheets previously described. The survey sheets are examined by various personnel who may request that the data be plotted against previous surveys for comparison. These plots are done manually. Hydraulics personnel then inspect the plots to determine if a problem may be imminent. The turnaround time (time from the date of survey to the time when plots are available for inspection) varies from two weeks to three months. One of the principal goals of this project was to develop a system whereby this turnaround time could be reduced and scour data made available in a useful format at near real time.

In order to accomplish this task, it was determined that a computerized scour management system would be necessary. The objectives of this system are:

1. To provide a means for interactive entry of data from the survey sheets.
2. To provide an interactive query facility.
3. To display the results of the query in a tabular as well as graphical format.
4. To interact with the scour analysis programs developed in phase 1 in order to analyze scour trend near bridge piers.

It was determined to implement SAMS on the Intergraph Interpro 32 workstation which makes use of the Data Management and Retrieval System (DMRS) and Interactive Graphics Design System (IGDS) packages supplied by Intergraph. This decision was made in full consultation with LADOTD personnel. The main reasons for choosing the Intergraph system for implementing the SDMAS were:

1. It provides a Data Base Management System (DMRS) and a Graphics system (IGDS).
2. It provides a library of software packages to assist the user and the applications programmer in accessing the above-mentioned systems.
3. It provides a facility for integrating applications in Data Bases, Graphics and traditional programming by providing interface software such as: HOL - Host Operations Language - Interfacing Fortran and DMRS, IGDS AS - IGDS Application Software - Interfacing Fortran and IGDS.

In the construction of SAMS, some original programming in FORTRAN and HOL was necessary. Thus, the final system is a composite of packages supplied by Intergraph and programs written for this project.

COMPARISON OF SCOUR MEASUREMENT EQUIPMENT

In order to substantially reduce the turnaround time for processing of the scour survey data, it would be helpful if the surveys could be taken in a digital format initially. One of the objectives of this study was to determine if this could be done on a cost-effective basis. It would also help in scour analysis if observations could be made during flood events. Thus the objective of this part of the study was to search the field of existing hydrographic survey equipment to determine the availability of systems with which surveys could be taken in a digital format both during and after flood events.

Accomplishing this task involved searching the relevant literature and contacting equipment manufacturers, hydrographic survey companies, and consulting engineers to determine the availability of the required equipment. Equipment manufactured or sold by Gulf Instruments, Inc., Odom Electronics, Ferranti, International Measurement and Control, Raytheon, and Motorolla was investigated and compared. Comparisons were made on the basis of cost-effectiveness and performance capability.

Many varied types of hydrographic survey systems were investigated. Some required the transducers to be boat-mounted while others could accommodate bridge- or pier-mounted transducers. The systems all consisted of various numbers of transducers, a digital recording box, location-finding equipment and a microcomputer to reduce the results to readable format. Possibilities varied from attaching a recording device to the current fathometer to digitally record the fathometer readings to purchasing a comprehensive system capable of printing underwater topographic maps of the surveyed area. A detailed analysis and comparison of these systems is provided in the Results section of this report.

RESULTS

TREND ANALYSIS EQUATIONS

Various forms of scour equations which appear in the literature were tested against the data for the three original bridges used in this study. It should be kept in mind that these equations were developed to predict maximum scour during flood events, while the scour observed by LADOTD is long-term degradation which encompasses all three types of scour. In addition, we are not attempting to predict scour but merely to analyze trends in the observed bottom elevations. However, these equations are imbued with certain hydraulic principles which may be applicable to this study. The forms of several of the most popular formulas were tested. These included the Shen (2), Coleman (7), Hancu (8), Subhash (4), Subhash-Neil (9) and Subhash-Fisher (4) equations. In these tests, the hydraulic properties shown in Table 2 were used. These properties are derived from the flood peak flows closest to the scour survey date. In some data sets, flow values that appeared to be outliers were removed. It is known that in the evolution of scour development, a maximum equilibrium scour depth is achieved under flood conditions. Additional discharge will cause no further scour during that particular event. Thus, the use of large floods in the data base (floods which did not result in disproportionate scour depths) would unduly bias the result and lead to erroneous conclusions. For this reason, floods which were judged to be in this category (based on comparisons of scour with smaller events) were excluded from the data base. These were: the 9/22/79 flood at LA-26 bridge, the 4/8/83 and 1/27/75 floods at the LA-10 bridge.

The performance of the equation forms tested was judged under the following criteria:

1. Statistical goodness of fit of the data on each individual bridge as determined by the coefficient of determination (R^2), the coefficient

of variation (C.V.) of the residual errors, and the results of the F tests on the individual parameters and on the whole equation.

2. The magnitude of the residuals of each data set.

3. The average results of these tests for the different bridges.

A coefficient was judged "bad" if it was not statistically significant in the F test at the 20% significance level. An equation was judged "bad" if all the coefficients were not statistically significant at the 10% level. "Bad" simply means that the particular term was not significant at this particular bridge location. The equations tested and the results yielded are shown in Table 4. The table shows the statistical comparisons of the major formulas in the literature. The statistics shown are the R^2 value, the coefficient of variation (C.V.), the computed F statistic (F^2) and the probability associated with that F value (P).

The results given in Table 4 show that of the equations tested, the Modified Shen and the Subhash-Fisher equations performed better than the others. Both equations combine basically the same parameters, i.e., the non-dimensional flow depth (Y/D) and the flow Froude number. The average R^2 for the Modified Shen equation for all three bridges was .79 and the average C.V. was 53.32. For the Subhash-Fisher equation, the average R^2 value was .79 and the average C.V. was 53.24. Obviously, these two equations, which encompass the same hydraulic parameters, perform about equally well in describing the observed scour data for the three test bridges.

EQUATIONS DEVELOPED FOR THIS STUDY

Several new equations which contain parameters that are believed to be important in the scour process were tested. Each term and each combination of terms included in these equations was specifically chosen because of its

TABLE 4

COMPARISON OF EXISTING SCOUR EQUATIONS

	R^2	CV	P	F^*	Comments
I. Shen: $d_s = K_1 \left[\frac{R_e}{100000}\right]^{K_2}$					
LA 25	0.69	67.93	0.056	8.74	
LA 10	0.43	87.53	0.013	8.51	
US 190	0.33	42.17	0.010	17.87	Bad K's
II. Modified Shen: $\frac{d_s}{D} = K_1 F^{K_2} \left[\frac{Y}{D}\right]^{K_3}$					
LA 26	0.71	80.23	0.197	4.23	Bad Eq., Bad K_3
LA 10	0.75	62.14	0.004	13.89	Bad K_1 and K_2
US 190	0.91	17.60	0.003	75.06	Bad K_2
III. Coleman (1971) $d_s = K_1 D^{K_2} \left[\frac{V^2}{2g}\right]^{K_3}$					
LA 26	--	---	---	---	Regression Prob.
LA 10	0.01	60.24	0.004	10.13	Bad K's
LA 190	0.04	65.63	0.067	5.47	OK 10%, Bad K's
IV. Hancu (1977): $\frac{d_s}{D} = K_1 \left[\frac{2V}{V_c} - 1\right] \left[\frac{V_c^2}{gD}\right]^{K_2}$					
LA 26	0.69	67.57	0.055	8.85	OK 10%
LA 10	0.73	59.72	0.001	22.31	
LA 190	0.32	42.55	0.011	17.53	Bad K's

TABLE 4 (continued)

	R^2	CV	P	F^*	Comments
V. Subhash-Fisher (1980): $\frac{d_s}{D} = K_1 [\frac{Y}{D}]^{K_2} [F - F_c]^{K_3}$					
LA 26	--	---	---	---	Regression Prob.
LA 10	0.75	62.46	0.004	13.73	Bad K_1 and K_3
LA 190	0.91	17.76	0.003	73.67	Bad K_3
VI. Subhash (1981): $\frac{d_s}{D} = K_1 [\frac{Y}{D}]^{K_2} [F_c]^{K_3}$					
LA 26	0.00	104.66	0.178	2.75	Bad Eq., Bad K's
LA 10	0.61	70.88	0.003	11.42	Bad K_1 and K_3
LA 190	0.65	32.34	0.005	24.82	Bad K_1 and K_3
VII. Subhash-Neil (1981): $\frac{d_s}{D} = K_1 [\frac{Y}{D}]^{K_2}$					
LA 26	0.02	120.46	0.312	1.76	Bad Eq., Bad K's
LA 10	0.68	65.6	0.002	17.89	
LA 190	0.88	17.93	0.000	107.91	

physical meaning as determined from a knowledge of the process. The equations tested were all linear either in their original form or logarithmically. Equations with both dimensional and non-dimensional parameters were tested; however, the better equations imply dimensional constants. Linear equations were chosen in order to keep the form of the relationships fairly simple because of the uncertain nature of the available data. The equation forms tested and their performance are given in Table 5.

From inspection of the results shown in Tables 4 and 5, several comments are possible. First, equations that incorporated only one independent variable to describe the flow did not result in good fits to the observed data. The pier Reynolds number, the flow Froude number and the depth were all tested as sole descriptors of observed scour without success. Among equations of this type one can cite the Shen (2) and the Subhash-Neil (9) forms. However, the results show that equations which incorporate three or more constants and several independent variables did not necessarily fit the data better than the simpler forms previously tried. Thus it would appear to be more important to identify a few significant variables in scour development, rather than the maximum number of such variables.

In a few cases, trends in the residuals were apparent. These trends may sometimes indicate that an important variable has not been included or that the derived equation is not significant. However, in this case it is felt that residual trends are unavoidable due to the correlation among the independent variables. Since the hydraulic properties of the flow (depth, velocity, Froude number, etc.) are to some extent all functions of the geometry of the cross section and the bridge, a degree of correlation among them is inevitable. Therefore, in studies such as this one, a certain amount of trend in the residual errors will have to be accepted.

TABLE 5

SCOUR EQUATIONS DEVELOPED FOR THIS STUDY

	R^2	CV	P	F^*	Comments
VIII. $\frac{d_s}{D} = K_1 + Y + K_2 \frac{R_e}{100000}$					
LA 26	0.90	44.45	0.031	13.81	Bad K_1
LA 10	0.68	88.80	0.019	7.32	
US 190	0.92	39.12	0.007	22.54	Bad K_2
IX. $\frac{d_s}{D} = K_1 F_c + K_2 [\frac{V^2}{2g}]$					
LA 26	0.92	37.82	0.019	19.64	Bad K_1
LA 10	0.86	58.17	0.001	21.72	Bad K_1
US 190	0.87	47.87	0.015	14.39	Bad K_1
X. $\frac{d_s}{D} = K_1 + Y + K_2 [\frac{V^2}{2g}] + K_3 \cdot \text{Days}$					
where "days" is the number of days between LADOTD survey and the flood					
LA 26	0.93	46.09	0.103	8.83	Bad Eq., Bad K's
LA 10	0.86	62.45	0.005	12.59	Bad K_1 and K_3
US 190	0.95	35.01	0.018	19.42	Bad K_1 and K_3
XI. $\frac{d_s}{D} = K_1 Y + K_2 [\frac{V^2}{2g}]$					
LA 26	0.93	37.65	0.019	19.85	Bad K_1
LA 10	0.86	58.20	0.001	21.70	Bad K_1
US 190	0.93	36.87	0.005	25.62	

The results show that Equation XI (Table 5) exhibits the best fit to the observed data for the three test bridges. This equation is:

$$d_s/D = k_1 * Y + k_2 \ (V^2/2g) \qquad \text{(XI)}$$

Inspection of this equation reveals that it possesses a great deal of physical meaning. The term $Y + V^2/2g$ is a measure of the specific energy of the incoming flow. Thus Equation XI directly relates the observed trend in the bottom elevations at a particular location to the energy of the peak flow of the flood event which occurred closest to the scour survey date. The estimates of the coefficients for the three original bridges are:

	LA 26	LA 10	US 190
k_1	.08832	.0008618	.01005
k_2	-63.012	-11.756	-3.368

This equation exhibited an average R^2 of .91 (91% of variance in observed scour explained) for the three bridges and resulted in an average C.V. value of 44.24. The equation is significant at the 5% level for all three bridges. Comparison of the relative performances of Equation XI and the Shen and Subhash-Fisher equations reveals that the developed equation performs significantly better in terms of both R^2 and C.V.

The equation was made dimensionally correct by removing the pier diameter (D) from the left side. The resulting equation:

$$d_s = k_1 * Y + k_2 \ (V^2/2g) \qquad \text{(XII)}$$

was actually an improvement over its predecessor. The statistics of this equation are:

	R^2	C.V.	P	F	Comments
LA 26	.93	37.64	.019	19.85	bad k_1
LA 10	.89	41.50	.000	29.56	
US 190	.96	25.37	.002	49.57	bad k_2

The coefficients of this equation are:

	LA 26	LA 10	US 190
k_1	.1033	-.1651	-.1131
k_2	-73.725	-33.076	2.597

Subsequently, this equation was tested on another bridge location. This bridge was the New Calcasieu River bridge on LA Route 26. The data for this location are shown in Table 6. Only 9 years of data are available at this location because this bridge replaced an old bridge at this location in 1979. The results of the regression analysis of Equation XII on these data are as follows.

R^2	C.V.	P	F
.82	46.10	.0765	6.821

The corresponding coefficients for this bridge were k_1 = -.2567 and k_2 = -55.651.

Inspection of the above results reveals that although the coefficients are similar in magnitude for all of the bridges the signs of some parameters are different as well as the actual values. This fact indicates that the terms in the specific energy equation combine in different ways to describe the hydraulic characteristics of the various bridges tested. Thus although the general form of the equation appears to be very accurate in describing the observed trend in the scour data, it will have to be calibrated for each individual bridge to which it is to be applied. The calibration procedure is outlined in Appendix I.

DETERMINATION OF A FACTOR OF SAFETY

In light of the uncertain nature of the data base used in the derivation of Equation XII and the uncertainty inherent in the regression analysis, it

TABLE 6

DATA BASE FOR NEW CALCASIEU RIVER BRIDGE (LA 26)

Scour Survey Date	Scour (ft)	Nearest Flood Date	Q (cfs)	V (ft/sec)	Y (ft)
10-9-80	--	10-01-80	547	.5	
10-13-81	+2.9	10-08-81	601	.59	7.91
10-05-82	-2.0	09-23-82	1130	1.72	3.88
10-20-83	-5.9	09-22-83	6750	2.04	18.21
09-14-84	+ .2	08-15-84	1260	.90	9.30
09-02-85	- .3	08-17-85	1890	1.13	10.37
02-07-86	-3.2	02-07-86	2490	1.15	12.76
11-03-86	- .3	11-02-86	826	.84	6.31
06-05-87	-4.6	05-17-87	3440	1.41	13.93
02-18-88	-1.3	--	--	--	---

was felt that a factor of safety should be developed for the equation. This safety factor was derived based on the published results of laboratory flume studies such as those cited previously. It was reasoned that since these studies predict the maximum scour to be developed for various flow conditions, they could be used to predict the maximum scour which could have developed in the time interval between the scour surveys used in this study. The results of various of these studies have been summarized by Melville (10). This summary is shown in Figure 4, taken from Melville's work. This figure is a plot of normalized scour depth vs. normalized velocity for various flow and sediment characteristics. It is noticed that these curves tend to come together in the range of large, normalized velocities and scour depths. Thus in this range, scour appears to be independent of sediment characteristics or even pier geometry. It should be possible, then, to use this curve to predict the maximum possible scour which might result from large flood events based only on the flow velocity during the event.

In the determination of the safety factor for Equation XII this curve was used to predict the maximum scour which might have developed during the maximum flood event which occurred during the interval between the scour survey dates. This value was then compared to the predicted value from Equation XII which was based upon the trend in the observed data. The percent difference is the factor of safety. This procedure was followed for each of the scour surveys and the results averaged for each bridge. The largest average error obtained for any of the bridges was 40%. It is suggested that in real world situations this factor be applied to estimates for all of the bridges in order to be on the conservative side.

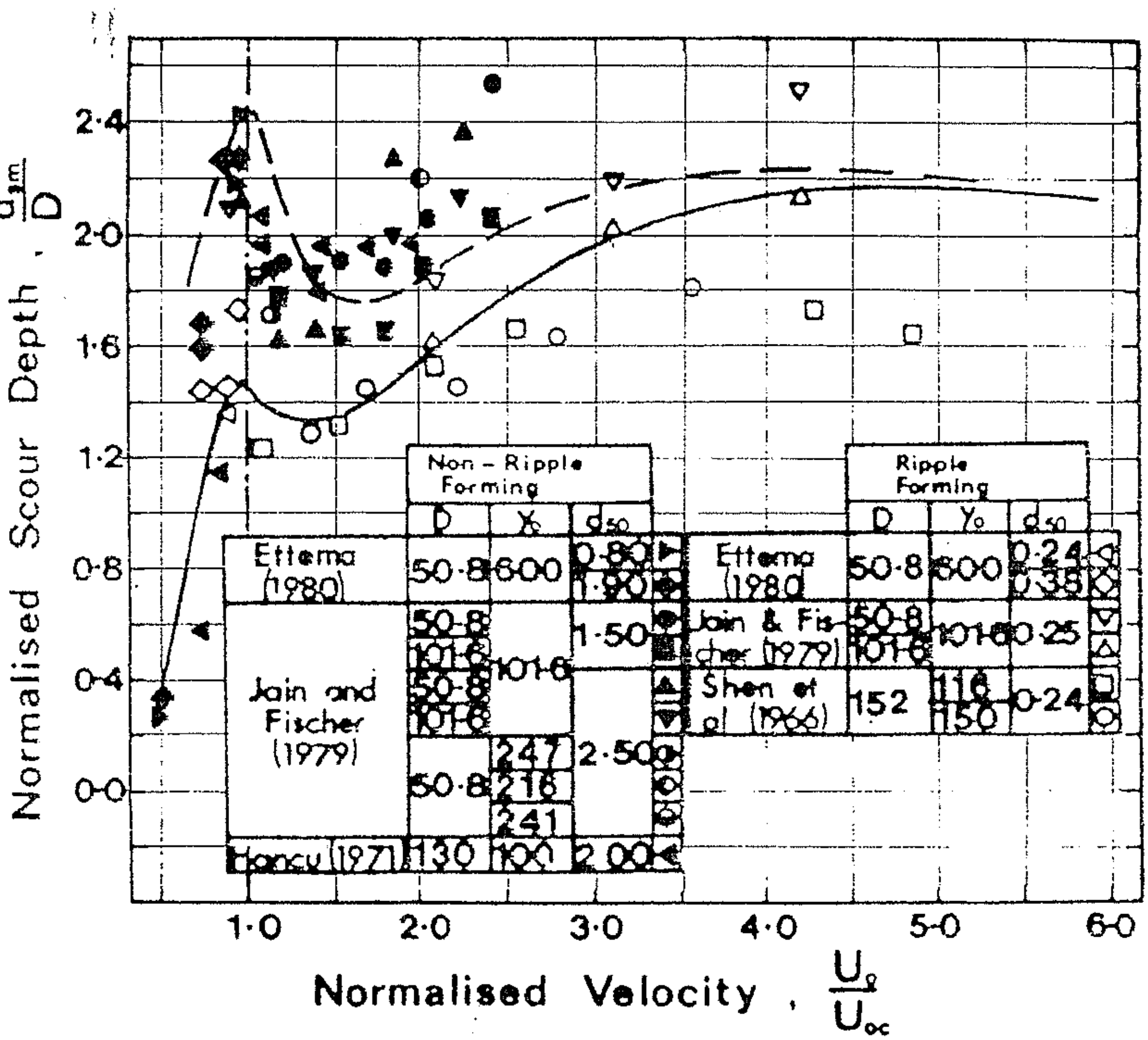


Figure 4. Maximum Scour Depth as a Function of Mean Flow Velocity For Relatively Deep Flows, Comparison With Data by Other Investigators (10)

VERIFICATION OF THE TREND EQUATION

In order to verify the accuracy of Equation XII, it was used to model scour trends from surveys taken subsequent to the development of the equation. Thus these data were not in the data base from which the equation was originally derived. Data were available for two of the three original bridges used in the study. These data, along with the results of the analysis, are shown in Table 7. In performing the analysis, a few of the large events had to be excluded because they exhibited velocities outside the range of those in the original data base. These events are marked with an asterisk in the table.

The results show that the equations generally gave results which matched the observed scour within the range of the safety factor of the equations.

Restrictions on Trend Equations

The equations developed in this study represent regression relationships based on the available data at each bridge site analyzed. The range of these data was necessarily limited. The range of the discharges, depths, and velocities of each bridge site is given below:

Bridge	Q_{max}	Q_{min}	Y_{max}	Y_{min}	V_{max}	V_{min}
Whisky Chitto	3540	1448	10.88	6.90	2.124	1.448
Pearl River	56500	9300	21.5	12.4	2.956	.869
Amite River	110000	4640	21.89	14.73	2.546	1.332
Calcasieu River	6750	826	18.21	3.88	2.04	.84

As with any regression equation, the equation recommended in this study should not be applied to data outside of the range of the data base which was used to derive it. The equation would likely be very unreliable if applied in these circumstances. The data base can be expanded by recalibrating the

TABLE 7

VERIFICATION OF SCOUR ANALYSIS FORMULA

Scour Survey Date	Observed Scour	Nearest Flood Date	Discharge	V	Y	Estimated Scour
		Pearl River at Bogulusa				
*03-08-85	-1.6	03-03-85	39800	5.46	19.49	--
10-11-85	-2.7	10-02-85	4090	1.35	11.05	-2.8
05-02-86	-8.0	03-24-85	25100	2.44	15.04	-6.9
08-22-86	-3.2	08-12-86	2550	.59	10.78	-2.7
*12-24-86	-2.5	12-01-86	38500	3.79	22.11	--
*08-21-87	-6.3	08-16-87	45500	4.10	25.30	--
		Whiskey Chitto Creek				
08-02-85	-4.0	07-04-85	647	1.74	3.07	-3.1
*01-31-86	- .5	12-15-85	5360	2.31	12.88	--
11-10-86	-2.1	11-07-86	711	1.65	3.39	-2.8
05-22-87	- .8	05-15-87	777	1.83	3.18	-3.5
*02-12-88	- .2	--	--	--	--	--

*Outliers

equation at regular intervals, say 3-5 years. In this way, additional data will be continually added to the data base at each bridge site.

It should also be kept in mind that the equations do not represent the maximum scour which would be expected to develop at a bridge site during a given discharge event. Therefore, it is strongly recommended that the factor of safety of 40% be applied to the results of the regression analyses before any decisions regarding a particular bridge are made.

Scour Analysis Management System (SAMS)

SAMS provides an interactive entry of data, an interactive query facility, and also provides programs for prediction of scour near a bridge for a given flood discharge. The system has been implemented on an Intergraph station and makes use of the DMRS and the IGDS packages previously described. The scour data management system consists of three subsystems:

- Data entry is done with the help of DWE (DMRS Worksheet Editor). This product is supplied by Intergraph and provides a "spreadsheet-like" interface to the data base. Function keys are programmed so as to make the task of data entry easier.
- Query is handled by a set of "Tutorials," "User commands," "Design Files," and fortran programs which provide graphical menus, perform query operations, and display the graphical output of the query.
- A set of fortran routines predicts the scour near a bridge for a given design flood.

The Scour Data Base contains a description of the various attributes and the storage space allocated to them. The functions of the Query Subsystem and a tentative description of the steps a typical user will have to go through are given in the following paragraphs. Samples of the graphical output for each of the query functions are also given.

User Input

The following discussion pertains to all the menus of the SAMS program. The SAMS program interacts with the user using two kinds of input, selection of an option from a menu and the entry of data from the keyboard. Options are selected by placing a DATA point (positioning the cursor and pressing the button D on the puck) in the corresponding box. Data entry fields on a menu are identified by a line in the corresponding fields in the menu. The cursor for data entry (which is an underbar) is automatically positioned at the beginning of each data entry field. Cursor control and editing features (like BACKSPACE, DELETE) enable the user to correct typing errors. The user can go to a previous field or go to the next field by using UP and DOWN arrow keys. Typing a RETURN at any field causes the data to be entered at the field and also positions the cursor at the next field. Note that using a DOWN arrow key to go to the next field does not cause the data to be entered.

SCOUR DATA BASE

The SCOUR data base consists of eight entities linked in a network structure. The entities are:

- BRIDGE - This entity contains static information about bridges. The attributes of this entity are:

Bridge Number	10 chars
Bridge Name	60 chars
District	Number between 0-999
Route	6 chars
Parish Code	2 chars
Structure Type	3 chars
Date of First Survey	6 chars (YYMMDD format)

Frequency of Survey	Number between 0-99 (in months)
Finish Grade Elevn.	Real number (in ft.)
Bridge Length	Real number (in ft.)
Basin Slope	Real number
Drainage Area	Real number
Precipitation	Real number
Design Storm 1	Number between 0-9999 (in years)
Discharge 1	Real number
Water Surface Elevn. 1	Real number
Average Velocity 1	Real number
Area of Opening 1	Real number
Backwater 1	Real number
Design Storm 2	Number between 0-9999 (in years)
Discharge 2	Real number
Water Surface Elevn. 2	Real number
Average Velocity 2	Real number
Area of Opening 2	Real number
Backwater 2	Real number
K1	Real number
K2	Real number

K1 and K2 are regression coefficients used for prediction of scour.

- SOUNDING - This entity contains the actual sounding data. The attributes of this entity are:

Bridge Number	10 chars
Pier/Bent Number	3 chars
Distance (from bridge)	Number between 0-999 (ft.)

Position	2 chars (US/DS/CL)
Bottom Elevation	Real number (ft.)
Date of Survey	6 chars (YYMMDD format)
Comment	50 chars

- PIER - This entity contains information about the location of the piers of a bridge, their type and their bottom elevations. This information has to be entered before the CROSS SECTION or HISTORY Query can be made. The reference point for measuring the distances can be arbitrarily fixed as the left-most pier of the bridge (looking upstream). The attributes of this entity are:

Bridge Number	10 chars
Pier/Bent Number	3 chars
Type	2 chars
Station (Distance)	Real number

(Distances increase as one traverses from left to right facing upstream)

Elevn. of Top of Footing	Real number
Elevn. of Bot. of Footing	Real number
Elevn. of Pile Tip	Real number
Comment	50 chars

- CROSS SECTION - This entity contains the cross section of a river near a bridge. This data is used for calculating the cross-sectional area, velocity, etc., required for scour prediction. The record corresponding to the left channel bottom should have "LEFT CHANNEL BOT" in its comment field. The record corresponding to the right channel bottom should have "RIGHT CHANNEL BOT" in its comment field. The attributes of this entity are:

Bridge Number	10 chars
Distance	Real number
Bottom Elevation	Real number
Date of Survey	6 chars (YYMMDD format)
Comment	50 chars

- o BRIDGE NOTES - This entity comments about a bridge made by a survey team. The attributes of this entity are:

Bridge Number	10 chars
Date of Survey	6 chars (YYMMDD format)
Line no	Number
Comment	50 chars

- o PARISH CODE - This entity contains a list of parishes and their two-digit codes. This information is used only at the time of data entry for reference. The attributes of this entity are:

Code	2 chars
Name	25 chars

- o PIER CODE - This entity contains information about the type of the pier and its corresponding code. The attributes of this entity are:

Code	3 chars
Type	25 chars

- o STRUCTURE CODE - This entity contains the type of structure and its corresponding code. The attributes of this entity are:

Code	2 chars
Type	25 chars

Main Menu QUERY

To activate the main menu, the user types UC=QUERY at the command line. This command invokes the menu shown in Figure 5. The default view for such menus has been set to 5, so the user switches to View 5 to choose options on the QUERY menu. The available options are:

- o REVIEW BRIDGES
- o SURVEY SHEET & PLAN
- o CROSS SECTION
- o LONGITUDINAL SECTION
- o HISTORY & SCOUR PREDICTION
- o END

Menu REVIEW BRIDGES

This menu (Figure 6) provides the user with information about bridges, such as the name of the bridge, number, route, structure, frequency of survey, etc. The specifications for this query are:

- o BRIDGE NUMBER
- o PARISH
- o ROUTE
- o DISTRICT
- o STRUCTURE TYPE
- o SURVEY FREQUENCY (months)

The user can omit any or all of the specifications by just typing RETURN at the corresponding key entry fields.

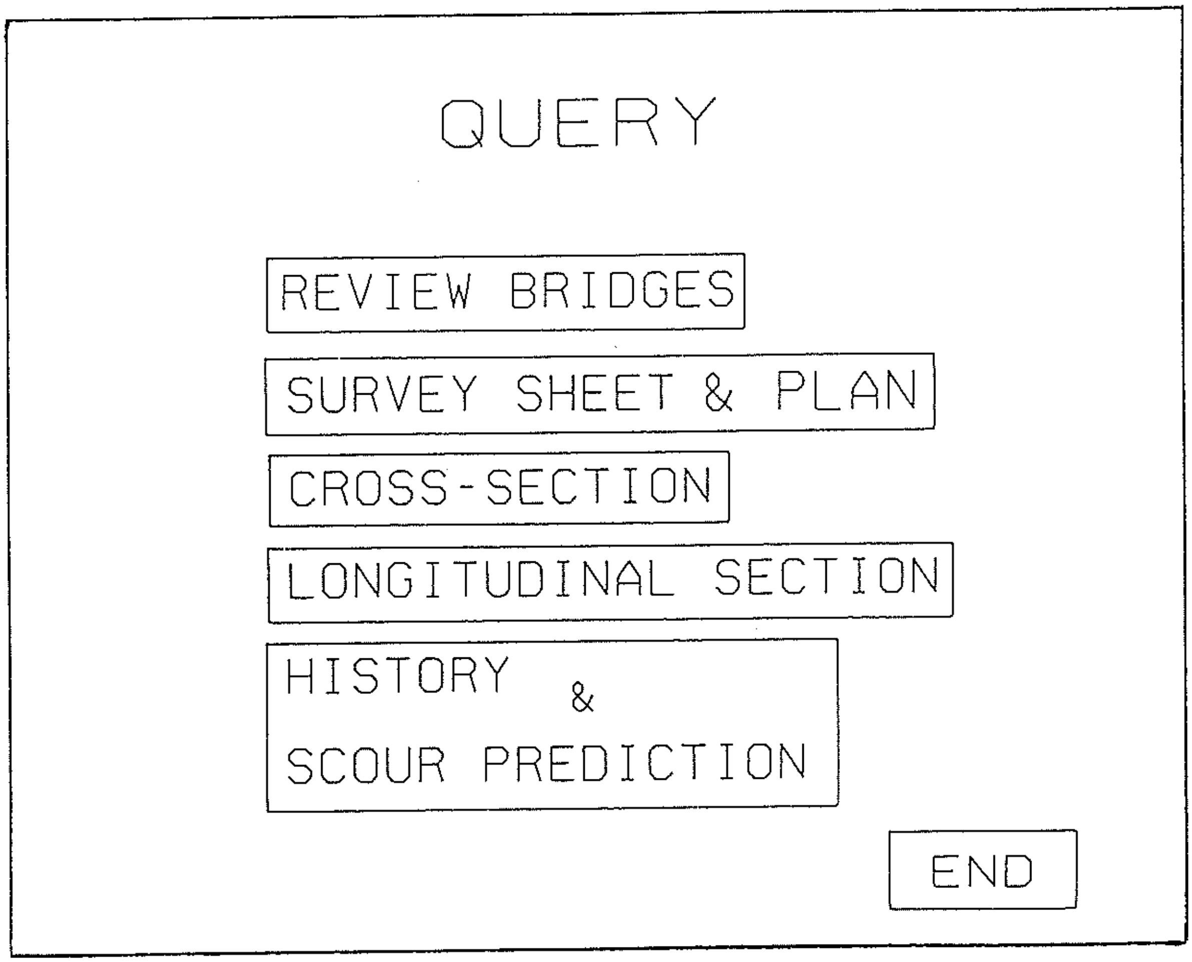


Figure 5. Main Menu Query

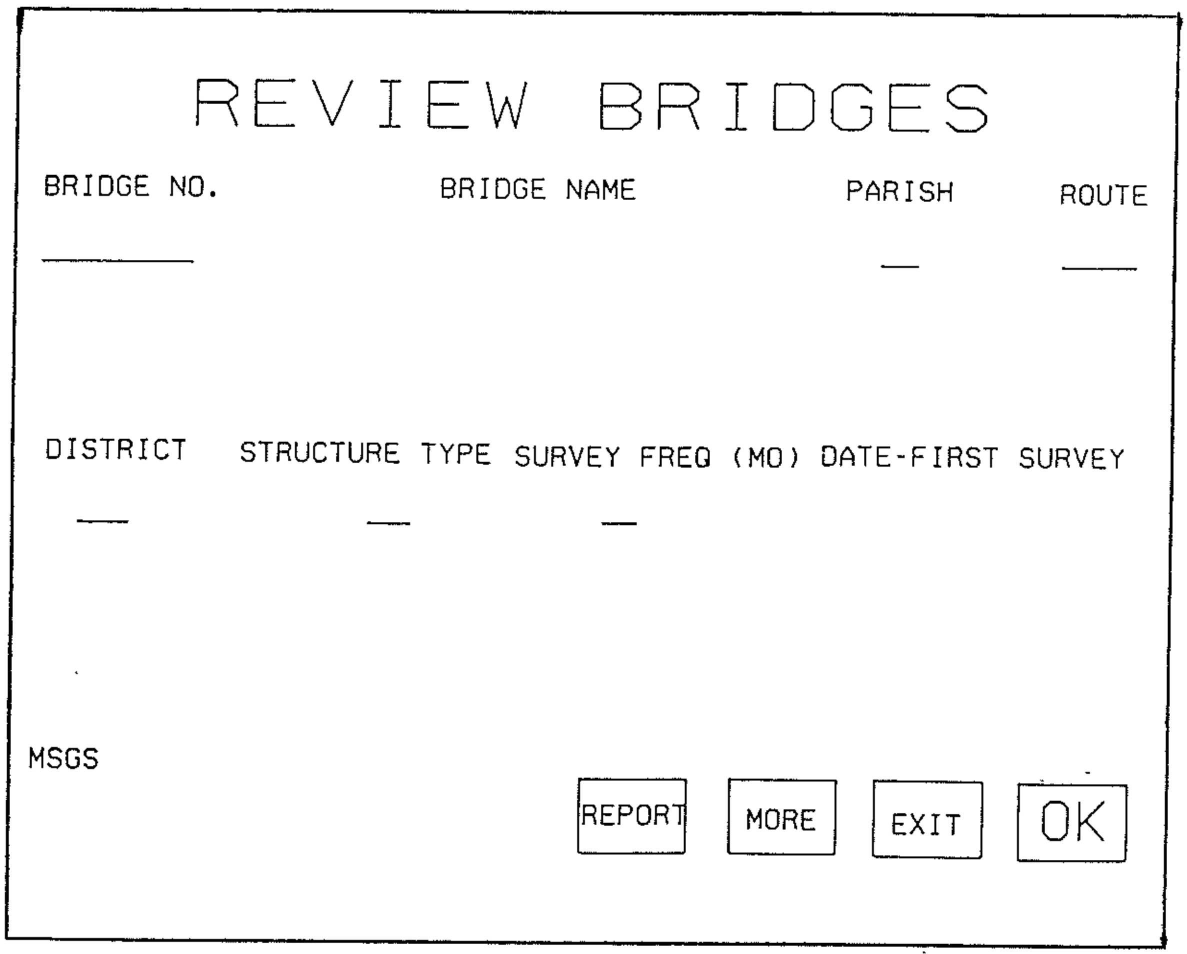


Figure 6. Menu Review Bridges

Menu SURVEY SHEET & PLAN

Using this menu (Figure 7), the user can obtain the survey sheet and a plan of the survey for a bridge on a given date. The specifications for this query are:

- o BRIDGE NUMBER
- o DATE OF SURVEY (in YYMMDD format)

If a graphical presentation of the survey plan is desired, the user selects the SURVEY PLAN option on the menu. A sample survey plan is shown in Figure 8.

Menu CROSS-SECTION

Using this menu (Figure 9) the user can obtain the cross-section of the river on a given date at a specified distance from the bridge. The specifications for this query are:

- o BRIDGE NUMBER
- o DISTANCE from bridge (in ft.)
- o POSITION (upstream US, centerline CL, or downstream (DS)
- o DATE OF SURVEY (in YYMMDD format)

A graphical presentation of the cross section is given in Figure 10.

Menu LONGITUDINAL SECTION

Using this menu (Figure 11), the user can obtain the longitudinal section of the river on a given date along a given pier. The specifications for this query are:

- o BRIDGE NUMBER
- o PIER/BENT NUMBER
- o DATE OF SURVEY (in YYMMDD format)

A graphical presentation of the longitudinal section is given in Figure 12.

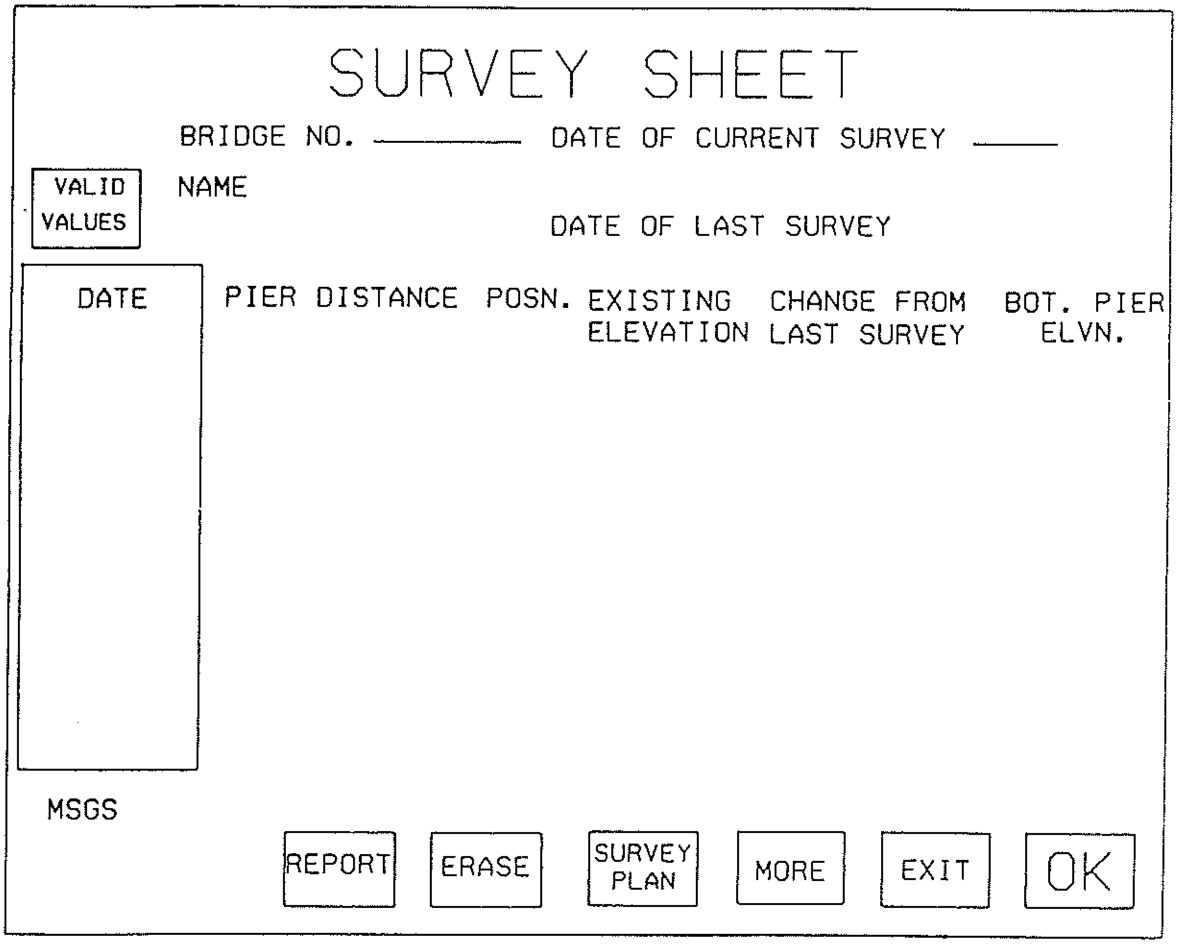


Figure 7. Menu Survey Sheet

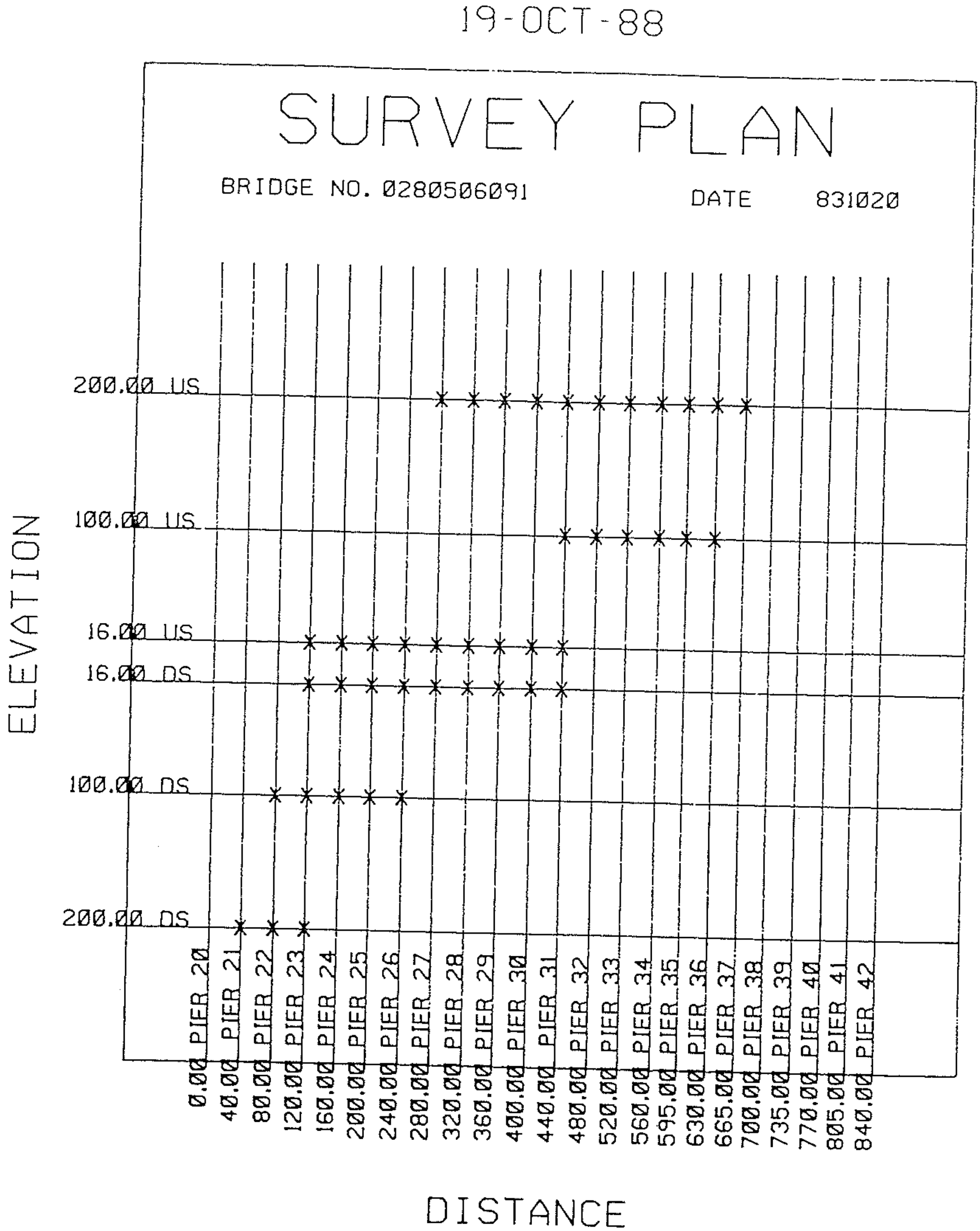


Figure 8. Bridge Survey Plan

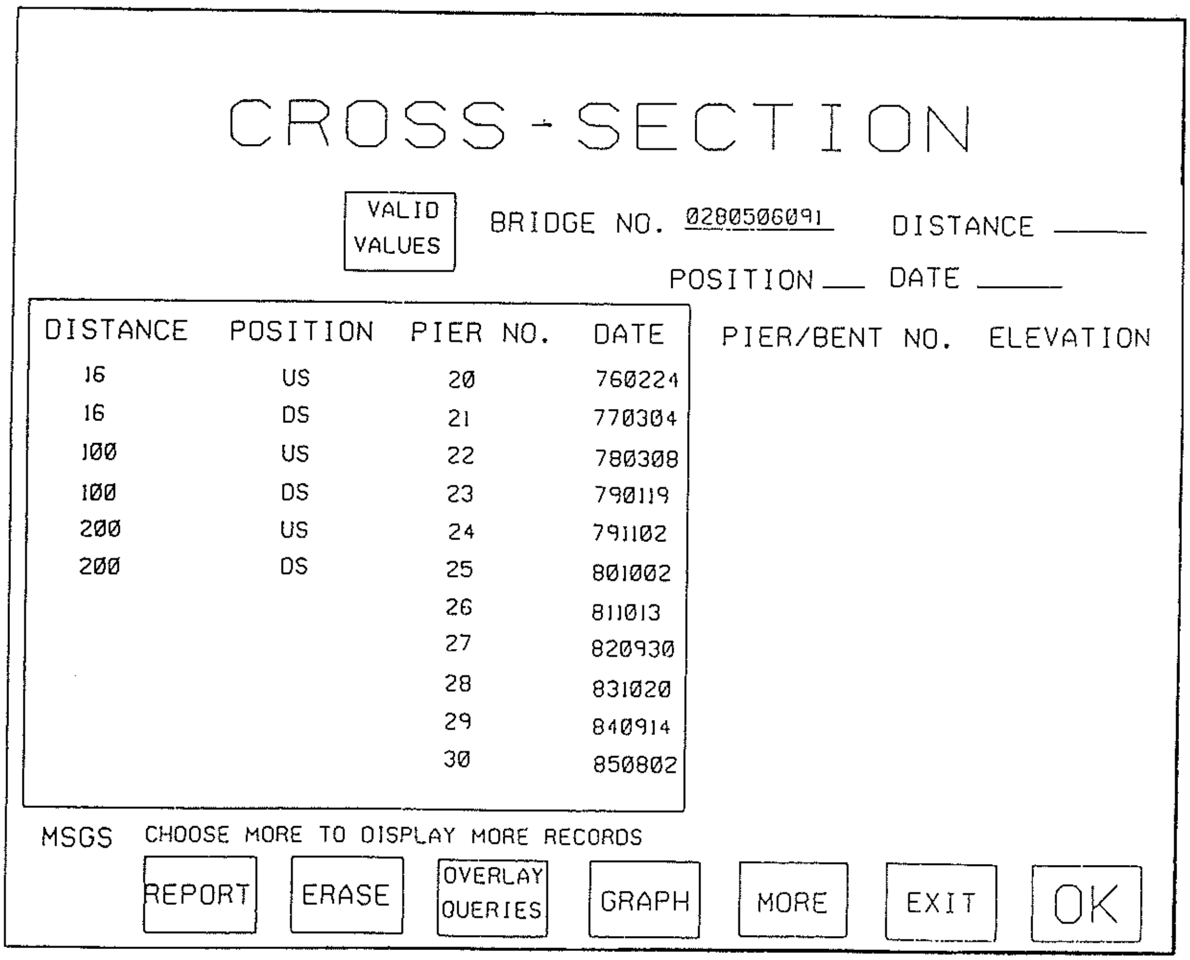


Figure 9. Menu Cross-Section

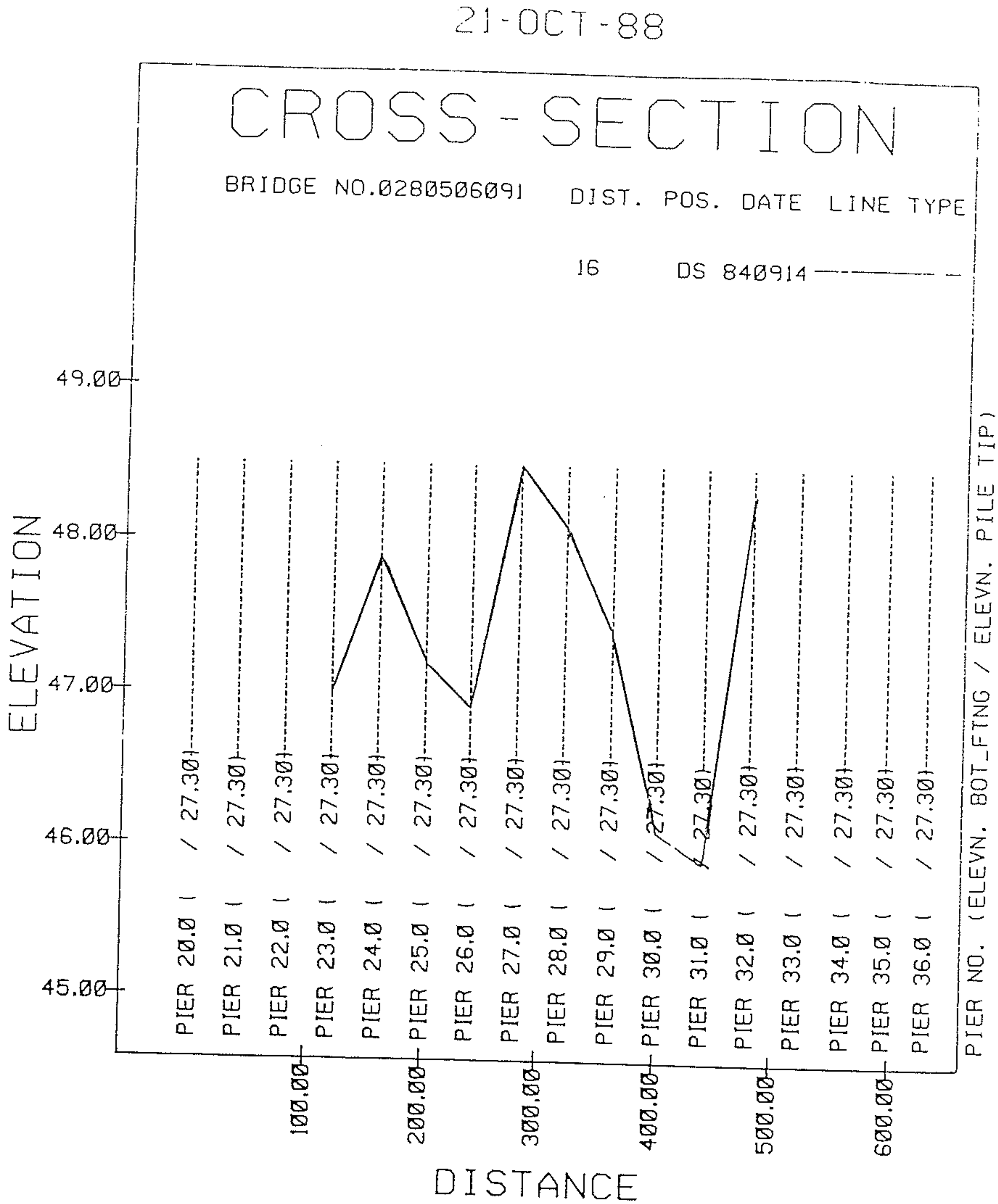


Figure 10. Typical Bridge Cross-Section

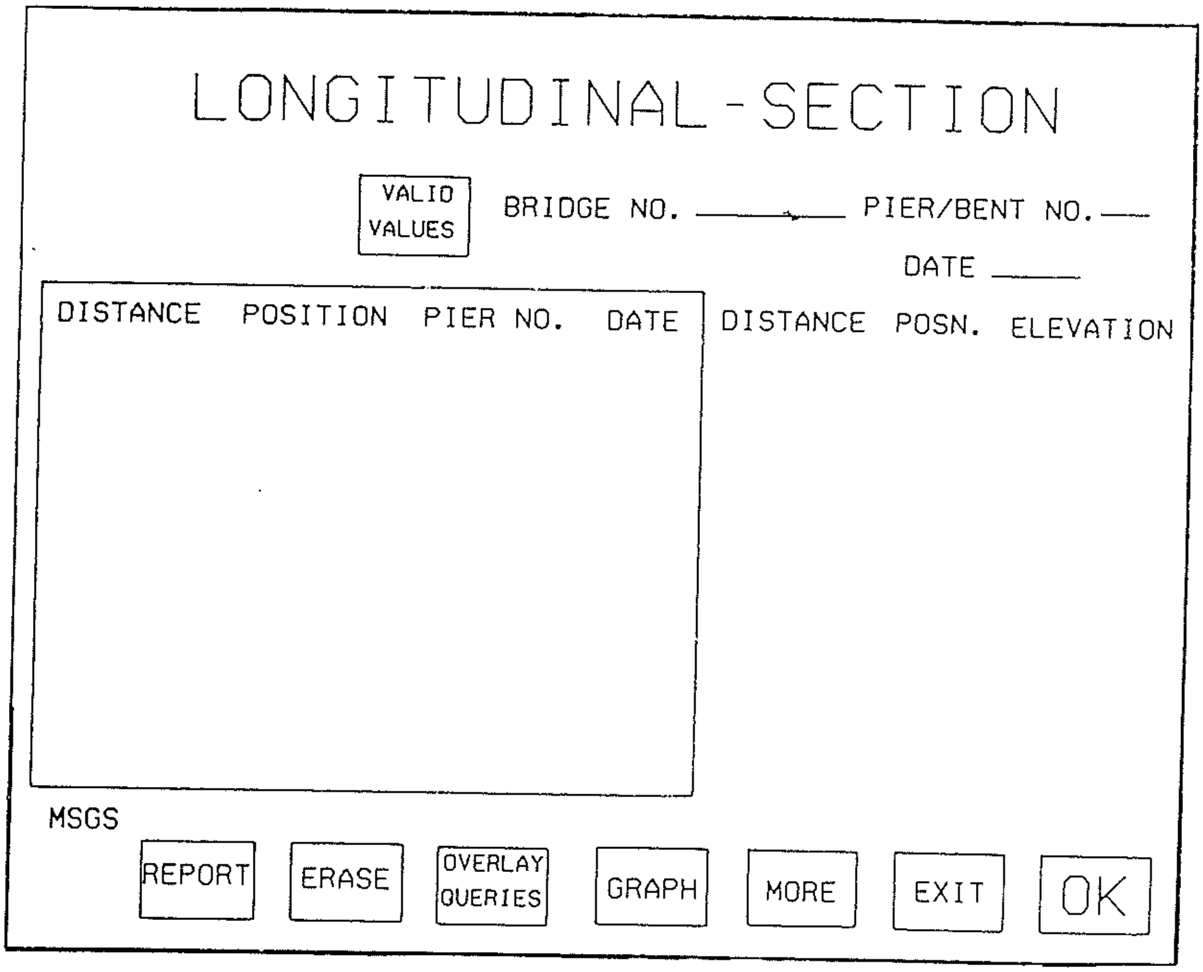


Figure 11. Menu Longitudinal-Section

21-OCT-88

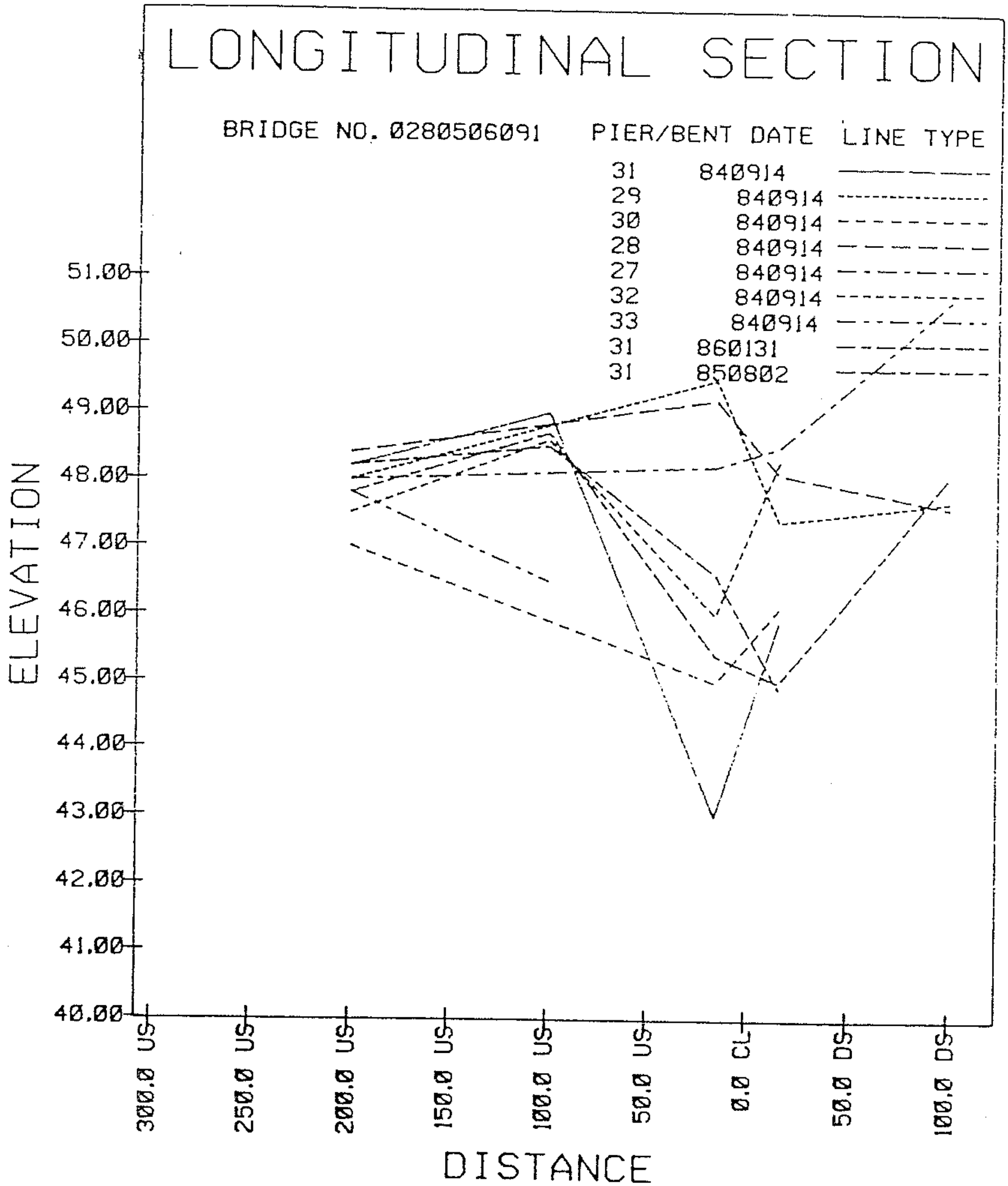


Figure 12. Typical Longitudinal-Section

Menu HISTORY AND SCOUR PREDICTION

Using this menu (Figure 13), the user can obtain the variation of the maximum scour depth in a given area over a period of time and also get an estimate of the scour likely to occur for a given flood. The specifications for the history query are:

- BRIDGE NUMBER
- UPSTREAM BOUND FOR AREA OF INTEREST
  - DISTANCE from bridge (in ft.)
  - POSITION (upstream US, centerline CL, or downstream DS)
- DOWNSTREAM BOUND FOR AREA OF INTEREST
  - DISTANCE from bridge (in ft.)
  - POSITION (upstream US, centerline CL, or downstream DS)
- LEFT BOUND - PIER/BENT NUMBER
- RIGHT BOUND - PIER/BENT NUMBER
- DATES OF INTEREST (in YYMMDD format)
  - INITIAL DATE
  - LAST DATE

The user chooses the QUERY (instead of OK) option to submit the specifications of the history query. The specifications for the scour prediction are:

- BRIDGE NUMBER
- FLOOD FLOW (in cu.ft./s)
- STAGE (ft.)

The user selects the SP option to obtain the predicted scour. A graphical display of scour (Figure 14) can be obtained by overlaying the results of scour prediction on a plot of a history query.

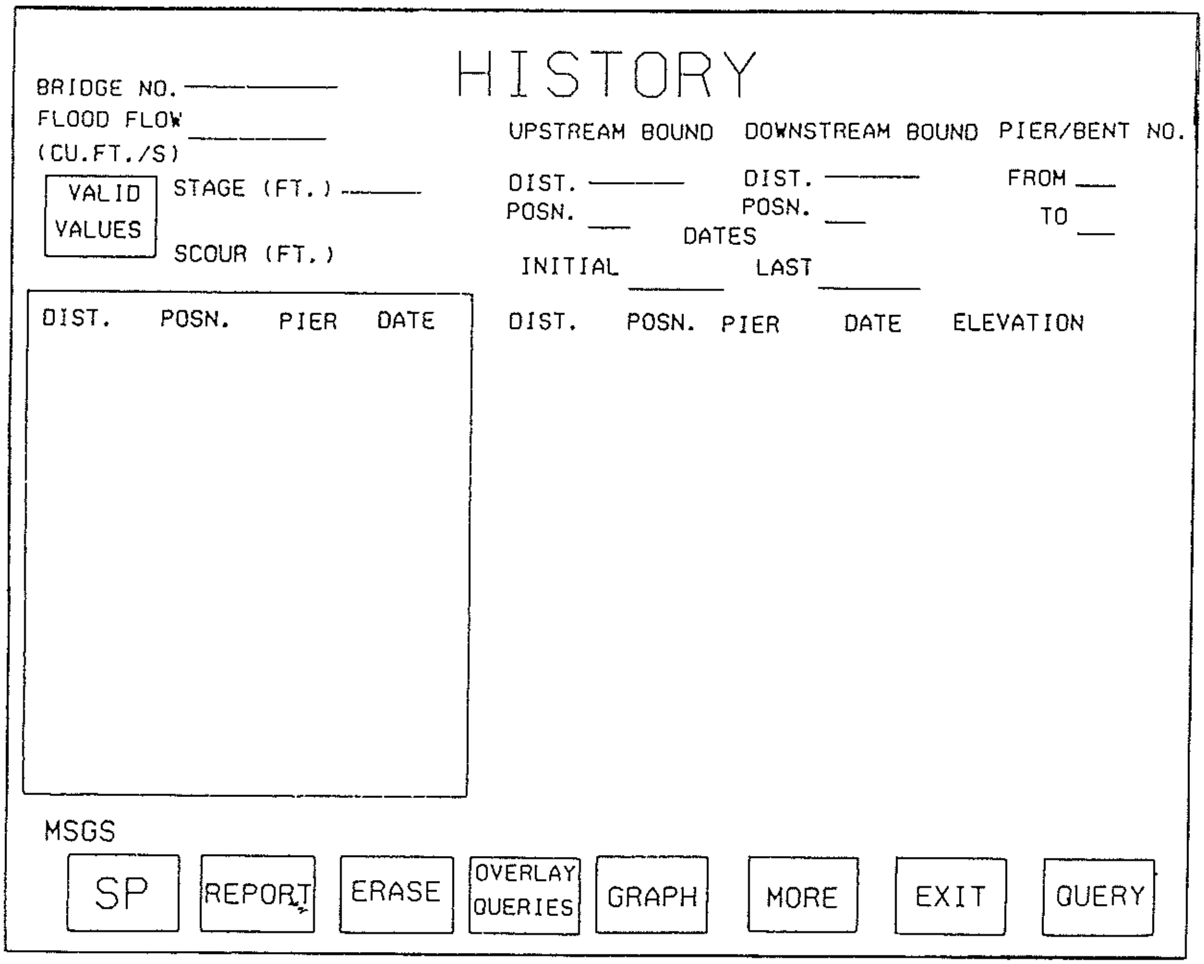


Figure 13. Menu Scour History

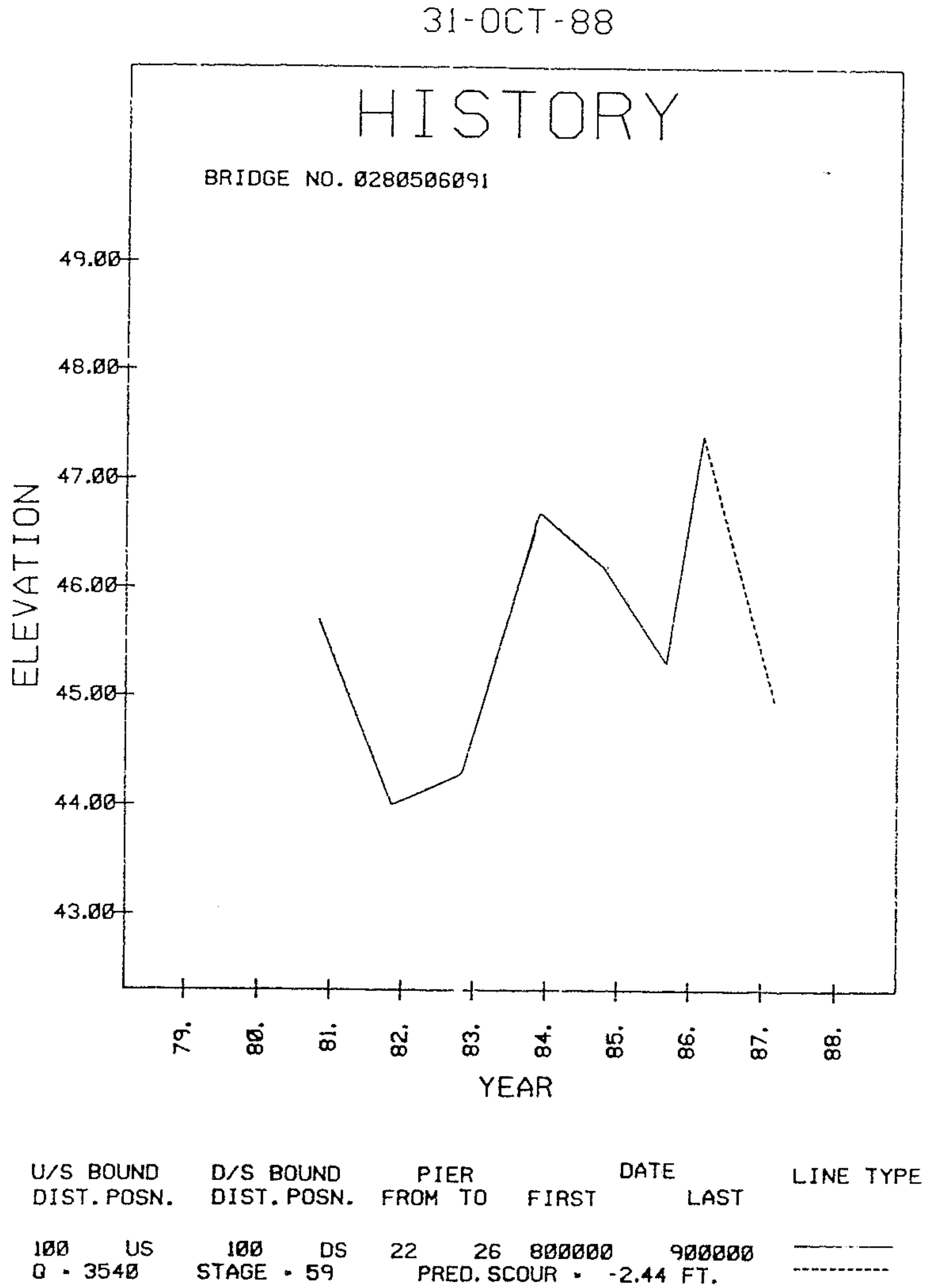


Figure 14. Typical Scour History and Prediction Plot

End

Selection of this option causes the program to end. The user has to return to the QUERY menu in order to end the program.

HYDROGRAPHIC SURVEYING EQUIPMENT: REVIEW AND RECOMMENDATIONS

At present LADOTD uses a Raytheon 719 Fathometer (current price $4,500-5000). This is an analog system; that is, its output is directed into a paper chart where the operator manually marks important points of reference. This is a cumbersome process. In addition, the data points are currently obtained at selected locations by manually adjusting the location of the boat along each cross section. Additional points are not ordinarily reported. Obviously, this is a disadvantage if further interpolations of the original data are required.

We have reviewed several types of hydrographic surveying equipment in order to provide a recommendation to LADOTD for augmenting its present capabilities with more efficient and state-of-the-art equipment. From these criteria, only digital (or microprocessor-based) systems were considered. These include equipment from the following manufacturers: Odom Hydrographic Systems Inc., International Measurement and Control Company, Raytheon, Motorolla, Comstar Hydrographic Systems, and Ferranti Ocean Research Equipment. However, in the following discussion we review equipment from only two of these manufacturers: Hydro I by International Measurement and Control Company and a series of systems by Odom. Some of the other manufacturers do not offer grated digital systems and therefore they are not discussed in our evaluation.

The following two hydrographic systems employ microprocessor-based, line-of-sight angle measuring and transmitting systems that are used in conjunction with a single range measuring system to provide continuous dynamic positioning of the survey vessel in relation to one known shore point. When deployed, the theodolite and transceiver, together with the remote unit of the range system, are located at a known shore point. The theodolite receiver and the master unit of the range system are installed aboard the survey vessel. As the vessel moves along a sounding line, distance between the shore station and the vessel is continuously measured while the shore operator tracks the onboard ranging antenna with the theodolite. Both types of data can be converted and displayed onboard or can be transmitted to a soft or hard disc of a computer system.

These systems will automatically collect an (X,Y) coordinate pair and a depth reading at pre-set distance intervals. Also, the equipment usually offers navigation information both for navigating to the starting point of a grid and for keeping on-line as soundings are being stored. Additional features include: interface to sounders, distance measurement (5 times per second or more), vertical and horizontal angle measurement (2 times per second or more), depths recorded at distance intervals, automatic computation of next line coordinates, parallel and nonparallel line modes, and real time data output.

These systems provide high accuracy and digital data. The advantage of digital data recording is that data are readily available to be displayed on board, edited, and stored on disk. This also implies that previously collected scour surveying data can be available on the vessel and be compared with the current data in real time. These systems can significantly reduce the production time for the LADOTD scour surveys.

These systems are ideal for small boat situations. The Hydro I system may be used with a 12 ft. boat; however, the Odom system with the ECHOTRAC fathometer requires a 22 ft. boat. Both systems are discussed in detail in the following paragraphs.

SYSTEM 1: Hydro I, a fully automated range azimuth surveying system

International Measurement and Control Company

300 E. Mineral Suite #5, Littleton, Colorado 80122

Tel: 303-797-7722

The Hydro I is a highly reliable and fully automated hydrographic positioning system that can be integrated with the existing sounding equipment and computer of the LADOTD to provide a complete hydrographic surveying package including computerized mapping.

Standard Hydro I equipment (costing $25,000)

- Hydro I Laser (range of 5,000 m, accuracy ±2 ft.)
- Lietz DT5 Theodolite (accuracy ±5 Arc Secc, resolution 10 Arc Sec)
- Quick Track Endless Tangent
- Shore/ship Voice and Data Links (range 5 miles)
- Navigator Box
- 12,000 Point Data Collector (x,y,z = 1 Point)
- Rechargeable Batteries w/chargers
- Omni-Directional Prism Cylinder without prisms
- RS232 Computer Interface

Configurations

Case 1. If LADOTD decides to keep using the currently owned Raytheon 719 fathometers, then to use the Hydro I package, they need to purchase and install the Fathometer Digitizer - DIGITRACE ($2,500) for each of their fathometers. These can be purchased by International Measurement and Control Company or from ODOM (see below). The advantage of getting them from ODOM is that ODOM is located in Baton Rouge and they can install the DIGITRACE in both of the LADOTD Raytheon fathometers. In this case, the cost will be (minimum configuration):

Standard Hydro I	25,000
Two DIGITRACE (@ $2,500)	5,000
Total	30,000

There are some more optional equipment for Hydro I. The one that needs to be mentioned is a set of prisms for $1,000, bring the total cost to $31,000.

Case 2. If LADOTD decides that the currently owned Raytheon 719 fathometers are not worthy of keeping, then they can get equivalent fathometers from Raytheon, or IMCC, for approximately $5,000 a piece. For two fathometers the total cost will be $31,000 + 10,000 = $41,000 (maximum configuration).

SYSTEM 2: Odom Hydrographic Survey System

Odom Hydrographic Systems Inc.

P.O. Box 927, Baton Rouge, La 70821

Tel: 504-769-3051

This system is composed of the following subsystems which can be configured in any desirable fashion:

The Positioning System

The positioning system is composed of the distance measuring unit and the shore station remote. Odom usually provides this system, which is manufactured by Racal, Delnorta or Motorolla. These systems are sold by Odom for about $18,000, assuming they are used equipment.

The Hydrographic Sounder

Odom's Hydrographic Sounder is called ECHOTRAC. It is a precision digital survey echosounder and it is composed of the recorder and the transducer. There are two models of ECHOTRAC Recorders: The single-frequency recorder that costs $17,160 and the dual-frequency that costs $18,260. The dual frequency recorded is recommended since it provides a valuable option. There are a number of transducers available, each designed with a certain frequency and angle. The cost of the dual-frequency transducer is $2,576.

The Azimuth Measuring System

Odom's azimuth bearing system is called AZTRAC. It is composed of a modified Lietz DT20 E theodolite, a shore station transmitter, and a receiver. The resolution of the system is 0.01 degrees (36 Arc Sec) and its range is 7 km. The cost of AZTRAC is approximately $18,250 (including cables, transit cases and receiver and transmitter antennas). A BCD Converter can be purchased for $6,261. This converter will provide the interface to the distance measuring system which has the capability of transmitting coded angle data through its existing RF data links. Without this converter, distance and azimuth data cannot be integrated.

The Hydrographic Data Acquisition System

Odom's version is called NAVTRACE and is composed of a processor, terminal, printer, plotter, and optional Hayes modem. The cost of the processor alone is $17,000. Prices are not quoted for the other peripherals since they vary with the type chosen.

Digibar

This is a device available from Odom for calibrating the velocity of sound for the ECHOTRAC. Its cost is $3,300.

The Echosounder Digitizer

Odom's version is called DIGITRACE and is internally mounted. DIGITRACE is a low-cost digitizer that can be installed inside most analog echosounders, such as the Raytheon 719, for digital depth displaying and output. It costs approximately $2,500.

Recommendation

Case 1 (minimum configuration)	
Positioning system	$18,000
Dual frequency ECHOTRAC sounder	18,260
Dual frequency transducer	2,576
AZTRAC - azimuth measuring system	18,250
BCD data converter	6,261
Navtrace processor (minimum unit for storing of data)	17,000
Total	$80,347
Case 2 (maximum configuration)	
As above	$80,347
Additional cost for complete NAVTRACE (estimate)	6,000
(this will help for onboard data review)	
Digibar	3,300
Total	$90,000

For backup, LADOTD may consider one more fathometer:

(Second) Dual frequency ECHOTRAC sounder	18,260
(Second) Dual frequency transducer	2,576
	29,836

This system is much more expensive. However, its capabilities are superior as well. If LADOTD considers replacing its old Raytheon fathometers, it may be desirable to choose Case 1 or Case 2 from ODOM. If onboard review of old data is desirable, then the complete NAVTRACE system is required (Case 2). Odom also has a multi-transducer (32) Sounder system (ECHOSCAN) capable of capturing a "bottom picture" without gaps. However, this feature is very costly ($25,000).

The ODOM equipment can be configured in a number of different ways. Data collection can be done by boat as discussed above. However, in this case the hydrographic surveys would have to be done after a flood event, as is currently done for safety reasons. This would not represent an improvement over current procedures in this respect. However, it is possible to configure the transducers in a pier-mounted system which could be maintained in position throughout a flood event. In this manner, the maximum scour developed during the flood could be measured.

Up to eight transducers could be mounted on the bridge piers and configured to cover specified areas upstream and/or downstream of the piers. These transducers would be portably mounted in brackets attached to the piers. In this way, they could be placed in position prior to the arrival of a flood event and then removed after the event for use elsewhere. The only equipment required for this configuration are the tranducers and recorder for a maximum cost of $38,868.

POSSIBLE FUTURE MODIFICATIONS

If the digital survey equipment recommended in this study is purchased, the present SAMS will have to be modified to accept the changed data format. As long as the data consist of individual survey points (X,Y,Z) taken at finite intervals, the basic components of the present system can be modified to accept these data. In this case, some software would have to be written or purchased to accept the data from the digital recorder and input it into the correct format for SAMS. SAMS, as currently constructed, will accept data at any grid spacing as long as the spacing is specified.

However, if the data are to be taken at a nearly continuous spacing such that underwater, three-dimensional topographic maps are to be drawn, the present system will not suffice. In this case, vendors of hydrographic survey systems and some other parties offer software packages to accomplish these tasks for a PC environment. In addition, other options are available, such as routines to compute volumes of scour or fill and to do detailed mapping of areas near a pier.

CONCLUSIONS AND RECOMMENDATIONS

The current procedure for scour survey and data analysis can be improved in many aspects. The vital part of the monitoring process is the time required for scour surveys to be taken, plotted, and analyzed. The system which resulted from this research project, if implemented and maintained, will drastically shorten this turn-around time and increase the reliability of the entire monitoring procedure. Furthermore, the analysis of the scour survey data will be made more objective by use of the scour analysis equations developed in this study. Therefore, to gain the maximum efficiency of the SAMS developed in this project, the following recommendations are made to LADOTD with regard to this study:

1. Staff gages should be placed at all important bridges which are to be monitored. Meaningful data analysis is impossible without discharge and stage information. Therefore, these gages must be carefully maintained and an accurate stage-discharge relationship determined for each gage. The USGS could be contracted to carry out these tasks.
2. Full cross sections should be taken at each bridge at each survey date. The current procedure of only reporting elevations relative to a few piers does not give a complete picture of the activity which is taking place at the bridge. A full section is necessary to get a complete picture and also to compute the necessary hydraulic parameters for scour analysis. These sections should be referenced to a known benchmark location so that they can be properly reproduced and updated. Only one section at each bridge is currently necessary and it should be taken a few feet (20-50) upstream of the bridge.

3. Eventually, sufficient sections should be taken both upstream and downstream of the bridge so that a bridge backwater model can be run. This is the most accurate method of determining the stage-discharge relationship for the bridges. With this relationship accurately known, water surface elevations could be used as an indication of when the bridge may be in danger of failure due to pier scour.

4. Serious consideration should be given to purchasing automatic digital scour measurement equipment. The equipment discussed in this study would greatly enhance the quality and reliability of the present method by providing the hydrographic survey data in a more real-time fashion. In addition, if the transducers were pier-mounted, actual measurements of scour during flood events could be obtained. These data would be highly useful and would greatly increase the safety of Louisiana's bridges.

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APPENDIX I

Calibration Procedure for Trend Equations

The recommended procedure for calibrating the scour prediction equation for a particular bridge based on the currently available data base is as follows:

1. Determine the location of the most significant scour activity (the "scour hole") for the bridge under analysis. The time history plots can be a great aid in making this determination.
2. Compile all of the available scour information for this location. Notice that this location may encompass more than one pier and more than one location u/s or d/s of the piers. Only scour, i.e., negative changes in the bottom elevation, should be used in the analysis.
3. From available flow records, determine the time and discharge of the closest flood event previous to each available scour survey. Unfortunately, this is a somewhat subjective judgment. The "flood" must be judged relative to the discharge which preceded it.
4. Obtain a channel cross section near the bridge site (preferably a few feet upstream) representing conditions as near the flood date as possible.
5. From the chosen flood event and cross section, estimate the average velocity and depth of flow using the software provided.
6. With the estimated flow depth and velocity from Step 5 and the scour values compiled in Step 2, regress the equation:

$$d_s = K_1 Y + K_2 \left(\frac{V^2}{2g}\right) \qquad \text{(XII)}$$

where

d_s = scour depth (ft)

Y = mean flow depth (ft)

V = average flow velocity (ft/sec)

K_1, K_2 = regression coefficients

The SAS package or any linear regression procedure can be used in these computations.