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Delineation of Tidal Scour through Marine Geophysical Techniques at Sloop Channel and Goose Creek Bridges, Jones Beach State Park, Long Island, New York

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 00-4033

Prepared in cooperation with the
NEW YORK STATE DEPARTMENT OF TRANSPORTATION

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Coram, New York
2001

U.S. DEPARTMENT OF THE INTERIOR
BRUCE BABBITT, Secretary

U.S. Geological Survey
Charles G. Groat, Director

For additional information
write to:

U.S. Geological Survey
2045 Route 112, Bldg. 4
Coram, NY 11727

Copies of this report may be
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Branch of Information Services
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FIGURES

CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATIONS

Multiply	By	To Obtain
	Length	
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Flow	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
	Velocity	
feet per second (ft/s)	0.3048	meter per second
	Other abbreviations used in this report	
	hertz (hz)	
	kilohertz (kHz)	
	minute (min)	
	second (s)	

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

Delineation of Tidal Scour through Marine Geophysical Techniques at Sloop Channel and Goose Creek Bridges, Jones Beach State Park, Long Island, New York

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Abstract

Inspection of the Goose Creek Bridge in southeastern Nassau County in April 1998 by the New York State Department of Transportation (NYSDOT) indicated a separation of bridge piers from the road bed as a result of pier instability due to apparent seabed scouring by tidal currents. This prompted a cooperative study by the U.S. Geological Survey with the NYSDOT to delineate the extent of tidal scour at this bridge and at the Sloop Channel Bridge, about 0.5 mile to the south, through several marine-geophysical techniques. These techniques included use of a narrow-beam, 200-kilohertz, research-grade fathometer, a global positioning system accurate to within 3 feet, a 3.5 to 7-kilohertz seismic-reflection profiler, and an acoustic Doppler current profiler (ADCP). The ADCP was used only at the Sloop Channel Bridge; the other techniques were used at both bridges.

Results indicate extensive tidal scour at both bridges. The fathometer data indicate two major scour holes nearly parallel to the Sloop Channel Bridge —one along the east side, and one along the west side (bridge is oriented north-south). The scour-hole depths are as much as 47 feet below sea level and average more than 40 feet below sea level; these scour holes also appear to have begun to connect beneath the bridge. The deepest scour is at the north end of the bridge beneath the westernmost piers. The east-west symmetry of scour at Sloop Channel Bridge suggests that flood and ebb tides produce extensive scour.

The thickness of sediment that has settled within scour holes could not be interpreted from fathometer data alone because fathometer frequencies cannot penetrate beneath the sea-floor surface. The lower frequencies used in seismic-reflection profiling can penetrate the sea floor and underlying sediments, and indicate the amount of infilling of scour holes, the extent of riprap under the bridge, and the assemblages of clay, sand, and silt beneath the sea floor. The seismic-reflection surveys detected 2 to 5 feet of sediment filling the scour holes at both bridges; this indicates that the fathometer surveys were undermeasuring the effective depth of bridge scour by 2 to 5 feet through their inability to penetrate the infilled sediment. Several clay layers with thicknesses of 3 to 5 feet were detected beneath the sea floor at both bridges. Most of the piers beneath Sloop Channel Bridge appear to be surrounded by riprap, but, in several areas the riprap appears to be slumping or sliding into adjacent scour holes. Similar slumping was indicated at the Goose Creek Bridge. Most of the sediment underlying the sea floor at both bridges is interpreted as a fine-grained, cross-bedded sand.

ADCP data from Sloop Channel indicate that the constricted flow beneath the bridge increases the horizontal current velocities from 2 to 6 feet per second. Total measured discharge beneath Sloop Channel Bridge was 41,800 cubic feet per second at flood tide and 27,600 cubic feet per second at ebb tide.

INTRODUCTION

Turbulent flow at bridge piers causes scour holes to develop, these in turn cause piers to fail and bridges to collapse. Local scour is the result of flow disturbances caused by emplaced objects such as pilings and piers (Gorin and Haeni, 1989). In May 1998, an inspection by New York State Department of Transportation (NYSDOT) of the Goose Creek Bridge (NYSDOT Bridge Identification Number [BIN] 1058509) (fig. 1), which connects Low Island with Green Island in southern Nassau County, revealed that one of the piers had settled sufficiently to separate from the overlying roadbed. This bridge was subsequently demolished, and a new bridge is under construction in its place. Previous fathometer surveys of the Sloop Channel Bridge (NYSDOT BIN 1058499), 0.5 mi south of Goose Creek Bridge, had indicated some degree of scouring, but the lack of resolution in horizontal positioning data from low-precision equipment combined with insufficient density of data and probable infilling of scour holes, made the delineation of scour holes uncertain. In July 1998, the U.S. Geological Survey (USGS), in cooperation with the NYSDOT, applied four marine geophysical survey techniques to delineate the extent of tidal scour at both bridges. Bathymetric maps produced from this study depict the distribution and extent of scour around the bridges. The similarity of scour patterns at Sloop Channel Bridge to those at

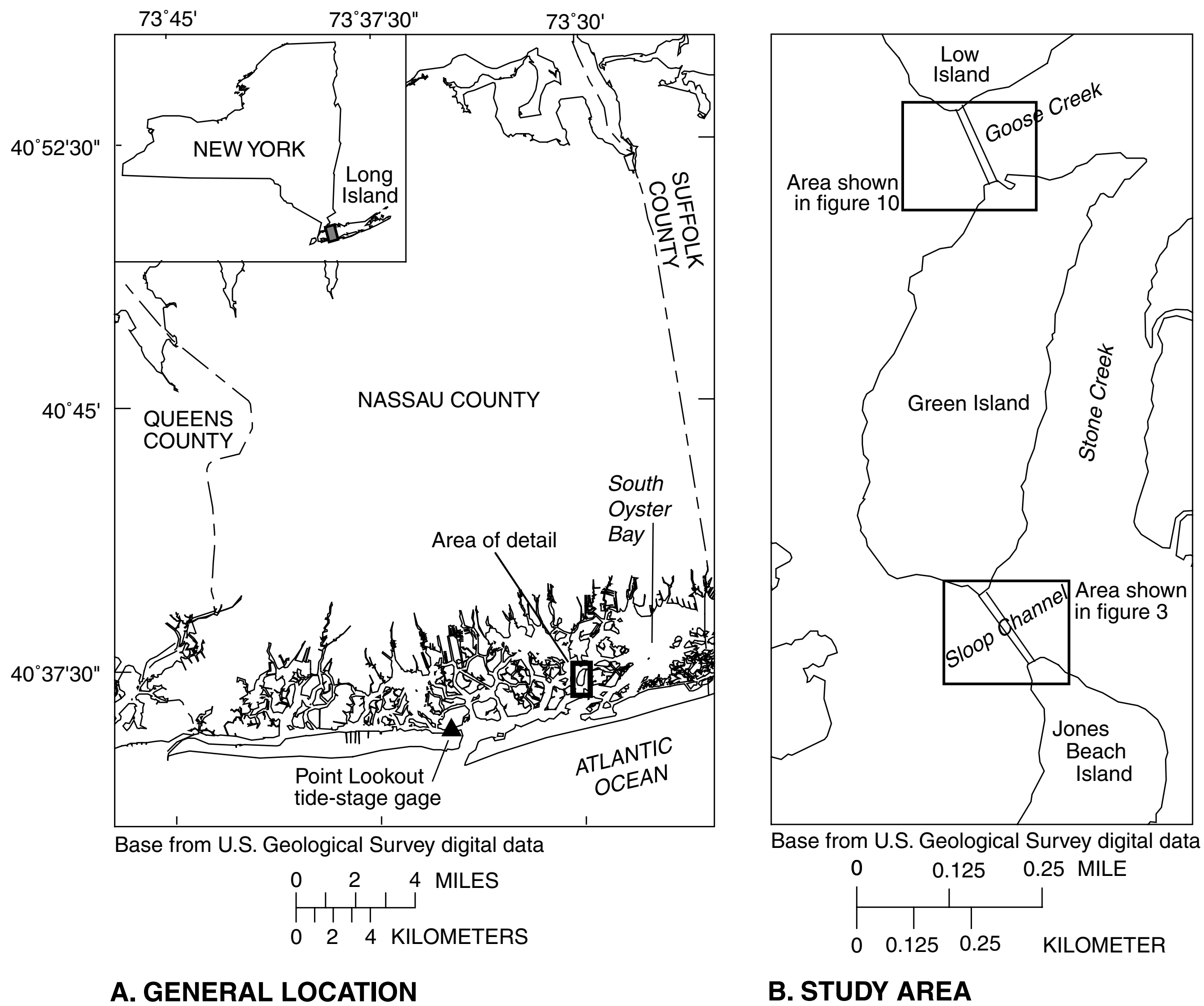


Figure 1. Location of Sloop Channel Bridge and Goose Creek Bridge study area, and of tide-stage gage, Nassau County, N.Y. A. General location. B. Study area.

Goose Creek Bridge indicate that tidal scour at bridge structures may be a regional phenomenon in the coastal waters of Long Island. Several bridge piers were found to be severely undermined by tidal scour during the July 1998 survey. This information was relayed immediately to the Federal Highway Administration and NYSDOT officials.

Accurate assessment of the extent of tidal scour at bridges requires a combination of geophysical techniques. Without exact location data and tidal corrections, fathometer surveys and diver inspections provide only qualitative information on the depth of scour holes and no information on their extent beneath the sea floor because the holes typically become filled with sediment after storms. Information on the sediment beneath the sea floor from seismic-reflection profiling is critical in evaluations of bathymetric surfaces and the extent of scour at bridges. In addition, the two-directional flow system (flood and ebb tides) in tidally affected areas such as Long Island's coast produces complex erosional patterns at bridge structures. Bridges in such areas require advanced surveying techniques such as global positioning systems (GPS), narrow-beam research-grade fathometers, continuous seismic-reflection profilers, and acoustic Doppler current profilers (ADCP's) to delineate the depth and lateral extent of bridge scour as well as the flow regime.

The study consisted of four components: (1) measurement of bathymetry beneath and surrounding the Goose Creek and Sloop Channel Bridges; (2) collection of high-frequency seismic-reflection data at both bridges; (3) measurement of flow- and ebb-tide current in three dimensions with an ADCP at the Sloop Channel Bridge, and (4) compilation and interpretation of all geophysical data to delineate the extent of tidal scour at both bridges.

Purpose and Scope

This report (1) depicts the sea floor beneath and surrounding Goose Creek and Sloop Channel Bridges, (2) delineates the geologic characteristics of the sediment beneath the sea floor through seismic-reflection profiles, (3) depicts the three-dimensional flow characteristics of the tidal currents at Sloop Channel Bridge, and (4) delineates the extent of tidal scouring and infilling of scour holes at both bridges in July 1998.

This report discusses the different geophysical techniques integrated to analyze the extent of tidal scour at the Sloop Channel and Goose Creek Bridges in southeast Nassau County, New York. The geophysical techniques included (1) use of a narrow-beam research-grade fathometer, (2) seismic-reflection surveys, and (3) ADCP measurements. All geophysical equipment were deployed from a 22-ft open-hull boat.

Location of Study Area

The Goose Creek and Sloop Channel Bridges are in southeastern Nassau County (fig. 1A). The Goose Creek Bridge (fig. 1B) is about 500 ft long and has two major concrete structures at its center and nine concrete support piers (fig. 2). The Sloop Channel Bridge, 0.5 mi to the south (fig. 1B), is about 625 ft long and consists of 17 rows of piers (bents) (fig. 2). Goose Creek and Sloop Channel are major conduits for tidal currents between South Oyster Bay and the Atlantic Ocean (fig. 1A). The two bridges connect Long Island to Jones Beach State Park on Jones Island, a major barrier island along the south-central shore of Long Island through Low and Green Islands in the bay.

Acknowledgments

The authors thank the officers and crew of the U.S. Coast Guard at Jones Beach for providing logistical support during the field operations for this study. Thanks are extended to the U.S. Geological Survey Branch of Geophysical Applications and Support for their technical assistance and use of the seismic-reflection survey equipment. The authors also thank the U.S. Geological Survey, Office of Surface Water, for technical assistance.

METHODS OF STUDY

Data were compiled from (1) bridge-construction records, (2) narrow-beam-fathometer surveys, (3) continuous seismic-reflection surveys, and (4) ADCP surveys. Additional information was obtained from previous NYSDOT fathometer surveys and construction reports. All marine-geophysical methods used in this study are based on similar principles of

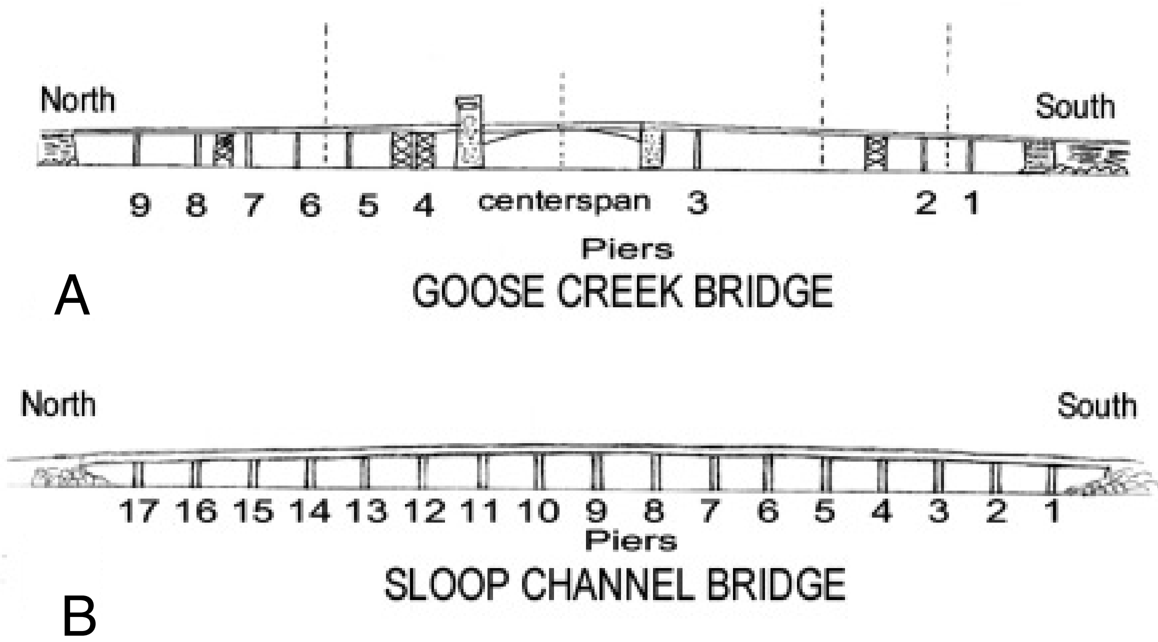


Figure 2. Pier-numbering system for piers during July 1998 seismic-reflection survey, Nassau County, N.Y. A. Goose Creek Bridge. B. Sloop Channel Bridge. (Locations are shown in fig. 1.)

wave propagation and reflection, wherein a signal is transmitted from the water surface into the water column and reflected back to the surface by the interfaces between materials of differing physical properties. Comparison of the reflected signals indicates the depth to the sea floor and the types of interfaces in the subsurface. Principles of fathometer and seismic-reflection surveys, and ADCP operation are briefly explained in the following sections.

Narrow-Beam Fathometer Surveys

Fathometer surveys were used to delineate the bathymetric surface features and the depth of the sea floor at both bridges. Fathometer surveys have been used in several USGS studies to delineate scour at bridges (Gorin and Haeni, 1989; Placzek and others, 1993; Haeni and Gorin, 1989; and Placzek and Haeni, 1995). The research-grade fathometer used in this study used a narrow, 3˚-beam, 200-kHz signal with an accuracy of about ± 0.1 ft after proper field calibration. Fathometers measure water depth by transmitting seismic energy through the water column and recording the arrival time of the reflected energy from the sea floor. Most fathometers use a 200-kHz seismic signal but differ in beam width (Placzek and Haeni, 1995). Fathometers provide accurate depth data but no information on the materials below the sea floor. All recorded fathometer depths were corrected to sea level with data from a continuously recording USGS tide gage at Point Lookout (fig. 1).

The location of the fathometer was tracked by a GPS, which uses a satellite differential system to produce accuracies within 3 ft at 2 standard deviations in the horizontal plane with a 1-Hz update rate. This system provides continuous latitude-longitude positions within 3 ft by applying L-band differential corrections transmitted from a geosynchronous satellite (David S. Mueller, U.S. Geological Survey, written commun., 1998). The horizontal (GPS) and vertical (fathometer) data were integrated into one data set by computer in real time. These high-accuracy data sets were then interpolated through software to produce contour plots of the data (figs. 4, 10).

Continuous Seismic-Reflection Surveys

A 3.5-to-7-kHz high-resolution continuous seismic-reflection profiling system was used to investigate the subsurface structure and lithology of sediments beneath the sea floor in the vicinity of the two bridges. Continuous seismic-reflection data were printed in real time on a thermal printer while being recorded on digital tape for later playback. An array of four transducers was used to transmit and receive the acoustic signal—two transducers were in “transmit” mode, and two in “receive” mode. The transducer array and associated transmitter, receiver, and recording equipment were deployed from a shallow-draft 22-ft boat. The tracklines were positioned through differential GPS.

Continuous seismic-reflection surveys have been used to interpret the depth and continuity of seismic reflectors and lithology (Haeni, 1986; 1988). Applications of this technique in bridge-scour studies have been described by Crumrine (1991), Brabets (1995), Bedingfield and Murphy (1987), Haeni and Gorin (1989), Gorin and Haeni (1989), Haeni and Placzek (1991), Placzek and others (1993), and Placzek and Haeni (1995). The continuous seismic-reflection system used in this study consisted of a graphic recorder, an amplifier/filter, power generator, a tuned 3.5-to-7-kHz transducer, a digital audiotape recorder, and a shallow-draft 22-ft boat.

Continuous seismic-reflection surveys use lower frequencies than fathometers. As a result, the seismic-reflection signal can penetrate the material beneath the sea floor, whereas the signal from the fathometers cannot. The seismic signals generated by the sound source travel through the water column and penetrate the sea-floor deposits. When a contrast in acoustic impedance (the product of the density and acoustic velocity of each medium) is encountered, part of the seismic signal is reflected back to the water surface, and part is transmitted to deeper material (Haeni,1986; Robinson and Çoruh, 1988). The signals reflected from the sea floor and underlying interfaces (such as changes in grain size, compaction, or sediment type) received by the hydrophone array produce an electrical signal that is amplified, recorded on digital tape, filtered, and plotted. The resulting seismic profile resembles a vertical geologic section, except that the vertical axis represents two-way traveltime, which is the time required for the seismic signal to travel from the source to the reflector and return (Haeni,1986). The acoustic velocity of the medium involved is used to convert the two-way traveltime of the seismic signal to an approximate depth scale. Seismic-reflection and refraction studies completed by the USGS in New York and New England indicate the average velocity of unconsolidated, saturated shallow deposits to be about 5,000 ft/s (Haeni, 1988; Reynolds and Williams, 1988); this value was used as an average velocity in this study.

Acoustic Doppler Current Profiler

Acoustic Doppler current profilers (ADCP’s) are deployed by boat to measure stream discharge, current velocities, and bathymetry in waterways that are too difficult or expensive to measure by conventional methods (Oberg and Mueller, 1994). The ADCP measures water velocities in three dimensions by measuring the Doppler shift of the ultrasonic acoustic pulses, known as pings, that are transmitted by four transducers situated 90˚ apart on the transducer assembly. The pings are transmitted at a 20-to-30˚ “beam angle” and are reflected back to the unit by particulate matter suspended in the water. The differences in the return times of the reflected pings are used to calculate the Doppler shifts and, thus, determine the flow vectors in three dimensions (Morlock, 1996; Oberg and Mueller, 1998). Similar pings are used to track the channel bottom to measure the boat velocity. The boat velocities are then subtracted automatically from the measured water velocities to calculate the true water velocities.

The ADCP transmits pairs of short phase-encoded acoustic pulses along four narrow beams at a known, fixed frequency (300-1,200 kHz) (David S. Mueller, U.S. Geological Survey, written commun., 1998). The reflected signal is discretized by time differences into several segments representing specific depth cells within the water column. The time-lag change and frequency shift (Doppler effect) between echoes are proportional to the relative velocity of the reflectors. The ADCP then computes three-dimensional velocity vectors for each depth cell. The cross-sectional area is computed together with the flow velocities, and the total discharge (ft^3/s) can be determined.

DELINEATION OF TIDAL SCOUR AT SLOOP CHANNEL AND GOOSE CREEK BRIDGES

Four geophysical techniques were used to delineate tidal scour and flow velocities in the vicinity of the Sloop Channel Bridge in July 1998. ADCP data were not collected at Goose Creek because the piers had been removed from beneath the bridge, changing the original flow regime.

Sloop Channel Bridge

The Sloop Channel Bridge, the southernmost of three bridges connecting the Nassau County mainland to Jones Beach Island, connects Green Island (an undeveloped island) to Jones Beach Island (the major barrier island that contains Jones Beach State Park) (fig. 1). It is a beam bridge about 72 ft wide and 625 ft long with 17 piers that are numbered 1 at the southern abutment through 17 at the northern abutment (fig. 2). The bottoms of the piles range from 41.9 to 58.2 ft below sea level. The outermost piers are referred to as "westernmost" and "easternmost" piers herein.

Fathometer Survey

A bathymetric map of the channel bottom in the vicinity of the Sloop Channel Bridge (fig. 3) was created from about 6,000 measurements made by a narrow-beam fathometer that provided depth readings at 0.5-second intervals. Depth values were automatically recorded and paired with continuous differentially corrected GPS locations, and the depth data were then contoured. The results of the narrow-beam fathometer survey indicate extensive scouring under and adjacent to the bridge (fig. 4). The contoured bathymetric map of Sloop Channel was produced by the Krieging[1] option of the surfer software (fig. 3). The map indicates two prominent scour holes roughly parallel to the bridge—one along the east side, and one along the west side. The maximum depth of these scour holes was measured to be 47 ft below sea level and to average more than 40 ft below sea level but, because fathometer signals are unable to penetrate below the sea floor, the true depth of scour is typically underestimated by fathometer data alone. The actual depth of scour below the sediment filling in a scour hole can be measured only by seismic-reflection surveys. The scour holes extend beneath and alongside most of the bridge and appear to have connected or joined beneath easternmost piers 9 through 14, and westernmost piers 11 through 13 (fig. 3). The deepest scour appears to be beneath westernmost piers 8 through 12, and easternmost piers 10, 12, and 13 (fig. 3). The near-symmetry of scour on both sides of the Sloop Channel Bridge suggests that flood and ebb tides produce equal amounts of scour. Moreover, the constriction of tidal flow by the 17 piers and underlying riprap at the Sloop Channel Bridge has caused the scour holes to extend toward the bridge in places, where they have undermined the riprap. For example, the -40-ft contours on both sides of the Sloop Channel Bridge (fig. 3) are close to meeting in the vicinity of piers 11 and 12. These data suggest deep and widespread scour at the Sloop Channel Bridge.

Comparison of the narrow-beam fathometer data with data from a previous (April 1998) fathometer survey indicates that the previous survey gave (1) poor coverage beyond the bridge structure, (2) insufficient data points for reliable contouring, (3) inadequate resolution, and (4) inaccurate positioning. The previous fathometer survey, when adjusted to sea level, underestimated the maximum depth of scour by almost 10 ft.

Seismic-Reflection Profiles

Seismic-reflection profiles of Sloop Channel imaged the sediments beneath the sea floor between piers 1 and 2, 4 and 5, 6 and 7, and 9 and 10 to indicate the amount of filling of scour holes, the extent of riprap under the bridge, and the types of sediment at each location.

Piers 1 and 2.—The profile between piers 1 and 2 (fig. 5) indicates a tight group of hyperbolic reflectors beneath the bridge; these are indicative of riprap that extends to about 50 ft beyond the westernmost and easternmost piers. The lack of signal penetration below these hyperbolic reflectors is due to the reflection and scattering of the seismic signal by the rock or riprap. Two well-developed scour holes are evident adjacent to the west and east sides of the bridge; seismic-reflection data from the west side indicate a probable scour hole filled with 2 to 3 ft of fine sand and silt, as indicated by nearly parallel

[1]Krieging is an option in the surfer software for creating contour maps from spatially oriented data.

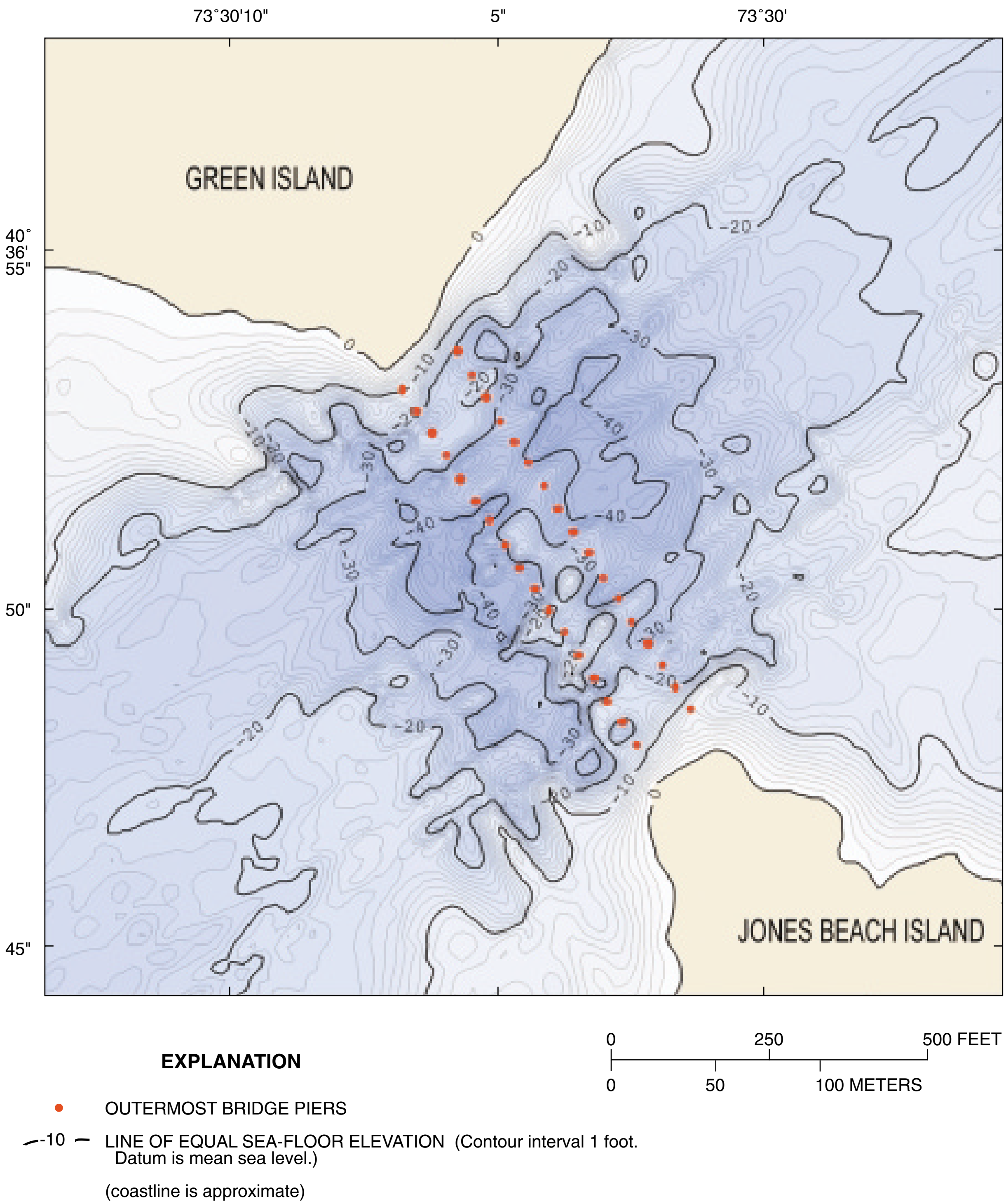


Figure 3. Sea-floor elevation at Sloop Channel Bridge, Nassau County, N.Y., July 1998. (Location is shown in fig. 1.)

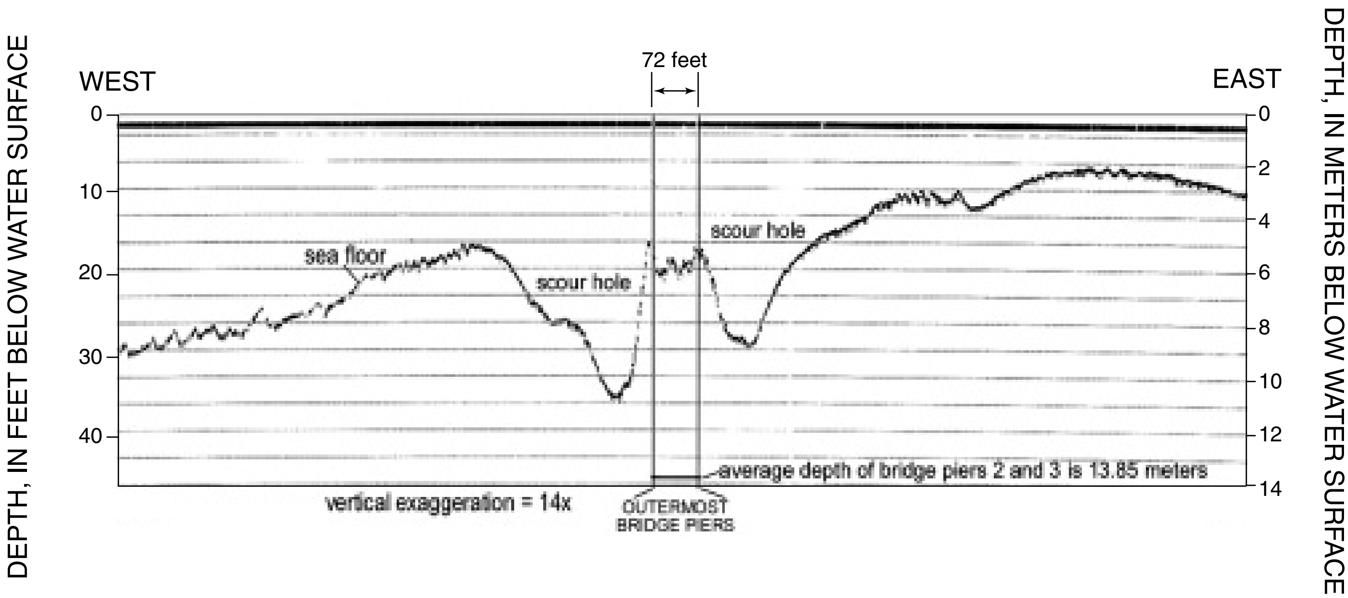


Figure 4. Narrow-beam fathometer profiles between piers 2 and 3 at Sloop Channel Bridge, Nassau County, N.Y., July 1998. (Location is shown in fig. 1.)

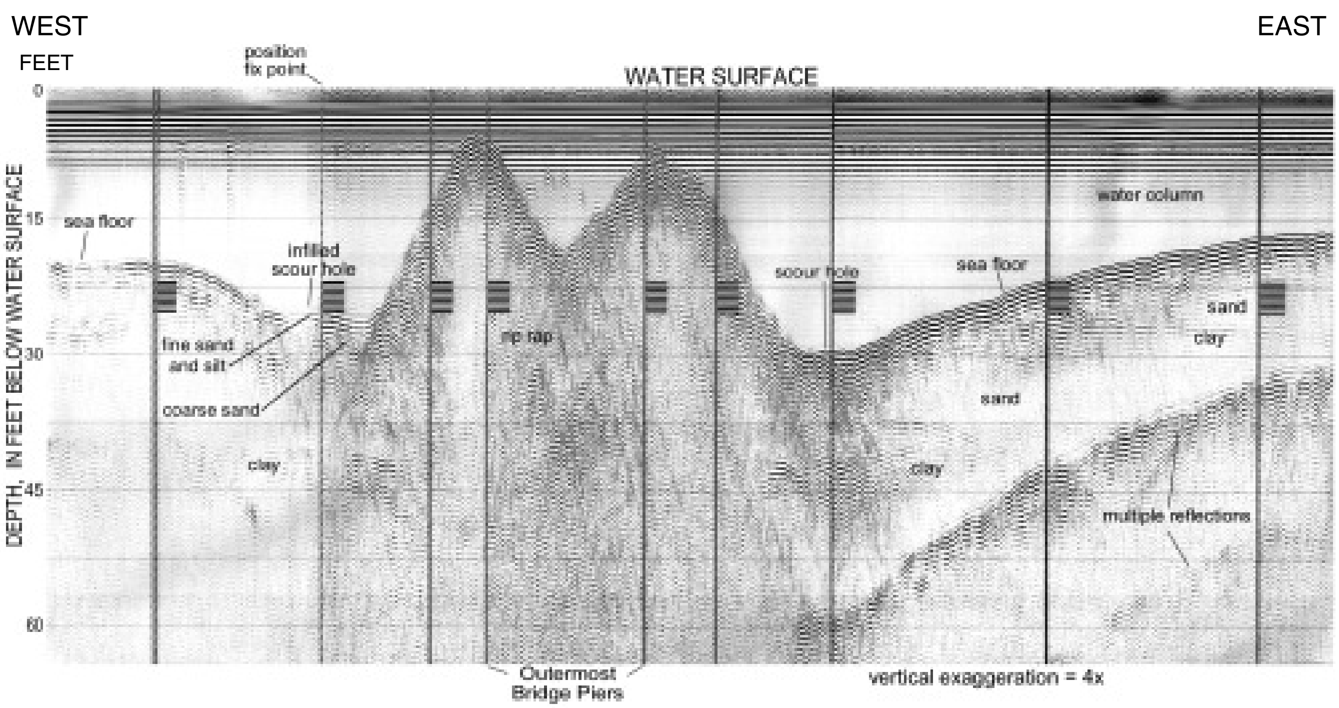


Figure 5. Interpreted high-frequency seismic-reflection profile between piers 1 and 2, Sloop Channel Bridge, Nassau County, N.Y., July 1998. (Location is shown in fig. 1.)

horizontal reflectors. This material forms a blanket of fine sand and silt on the sea floor and is underlain by coarse sand, as indicated by chaotic reflectors. The western infilled scour hole extends about 5 ft below the sea-floor surface; it is 36 ft wide beyond the riprap adjacent to the bridge and extends to about 30 ft below water surface, or 5 ft deeper than can be detected by narrow-beam fathometer alone. The eastern scour hole has 2 to 3 ft of nearly parallel horizontal reflectors that indicate a blanket of fine sand and silt. Below this horizon is an assemblage of sand and two clay horizons—one at 25 ft below water surface, and the other at about 42 ft below water surface—as indicated by a series of nearly parallel horizontal reflectors. The shallow clay is 2 to 3 ft thick, and the deep clay is 4 to 5 ft thick. Both clay units appear to increase in depth toward the east. The shallow clay is truncated by the eastern scour hole. The deep clay extends throughout the entire profile but was not imaged beneath the riprap as a result of signal attenuation.

Piers 4 and 5.—The seismic-reflection profile between piers 4 and 5 (fig. 6) indicates a tight group of hyperbolic reflectors indicative of riprap beneath the bridge. The variation in the height of the riprap beneath the bridge is probably due to an undersea landslide or slumping of riprap on the eastern side of the bridge. This slumping of the riprap is probably due to undermining by the east-side scour hole. The riprap has partly filled the scour hole to produce an asymmetrical V-shaped depression. As a result of this depression, the easternmost piers of the bridge in this area are exposed to a depth of 30 ft below water surface. The riprap appears to extend to about 40 ft west of the westernmost pier and to about 26 ft east of the easternmost pier. Two scour holes can be seen in figure 6—one on the west side of the bridge, and the other on the east side. The western scour hole, which extends to about 41 ft below water surface, appears to have nearly parallel horizontal reflectors indicative of fine sand and silt infilling the hole with 2 to 3 ft of material that blankets the surrounding area, except under the bridge, where high flow velocities prevent deposition. The eastern scour hole, which extends to about 37 ft below water surface, is also partly filled with 2 to 3 ft of soft, fine sand and silt, as indicated by the nearly parallel horizontal reflectors. The maximum depths of both scour holes are 2 to 3 ft deeper than would have been indicated by narrow-beam fathometer alone. Below these horizons is an assemblage of sand units and a clay horizon, as indicated by chaotic and nearly parallel reflectors, respectively. The clay horizon is about 40 ft below water surface, 4 to 5 ft thick, and probably extends throughout the entire profile.

Piers 6 and 7.—The seismic-reflection profile between piers 6 and 7 (fig. 7) indicates features similar to those between piers 4 and 5 (fig. 6). Two scour holes —one to the west of the bridge and one to the east— are separated by a group of hyperbolic reflectors that are indicative of riprap. These reflectors extend to about 74 ft west of the westernmost pier and to about 30 ft east of the easternmost pier. The differences in the height of the riprap beneath the bridge are attributed to slumping caused by the undermining of the riprap at the adjacent eastern scour hole. The eastern scour hole appears to be filled with 4 ft of fine sand and silt, as indicated by the nearly parallel horizontal reflectors. This material appears to blanket most of the surrounding areas on both sides of the bridge. The eastern scour hole extends to about 45 ft below the water surface—4 ft deeper than could have been detected by narrow-beam fathometer alone. The asymmetrical shape of the eastern scour hole suggests that riprap from beneath the bridge has either slumped or slid into the hole. The western scour hole, which extends to about 35 ft below water surface, also is partly infilled by about 3 ft of fine sand and silt. Beneath the sea floor is an assemblage of sand and clay horizons. Nearly parallel horizontal reflectors at about 41 ft below water surface on the west side of the bridge indicate a continuous clay horizon about 5 ft thick and truncated on the east side by the eastern scour hole. Beneath the riprap, the clay horizon reflectors appear to end and begin abruptly as a result of scattering and attenuation of the signal by the riprap.

Piers 9 and 10.—The seismic-reflection profile between piers 9 and 10 indicates extensive scouring of the sediment and undermining of riprap beneath and adjacent to the bridge (fig. 8). Hyperbolic reflectors indicative of riprap appear to extend to about 32 ft east of the easternmost pier and to about 25 ft west of the westernmost pier. The westernmost piers are exposed to a depth of 40 ft below water surface. The two large scour holes to the east and west of the bridge (fig. 4) appear to be extending toward one another. The eastern scour hole appears to be infilled with a blanket of 3 to 4 ft of fine sand and silt, as indicated by the

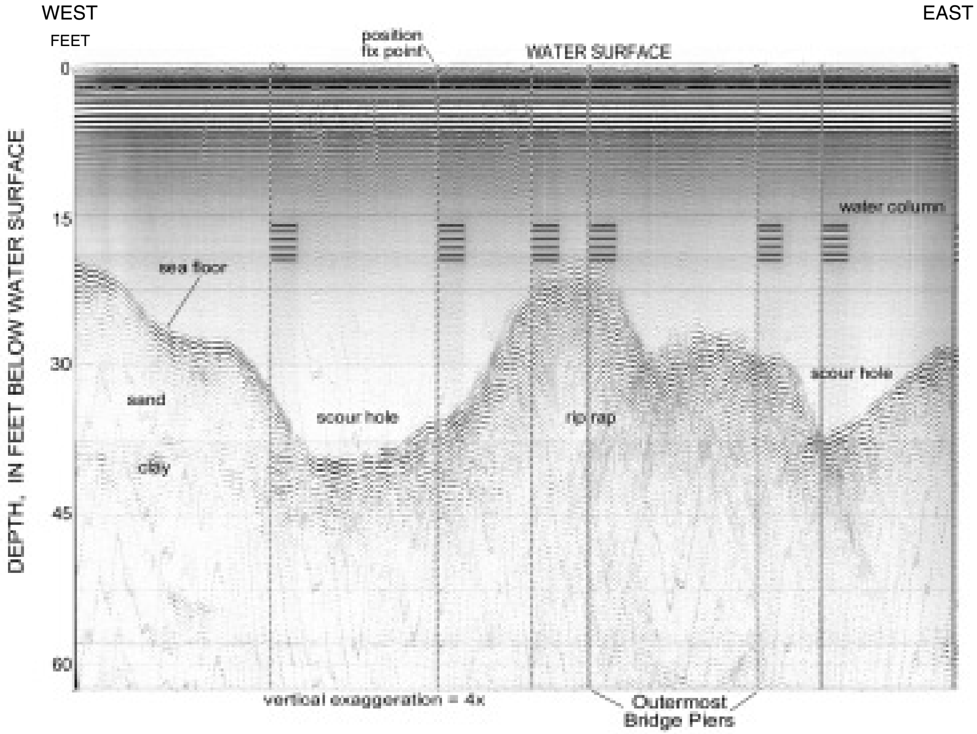


Figure 6. Interpreted high-frequency seismic-reflection profile between piers 4 and 5 at Sloop Channel Bridge, Nassau County, N.Y., July 1998. (Location is shown in fig. 1.)

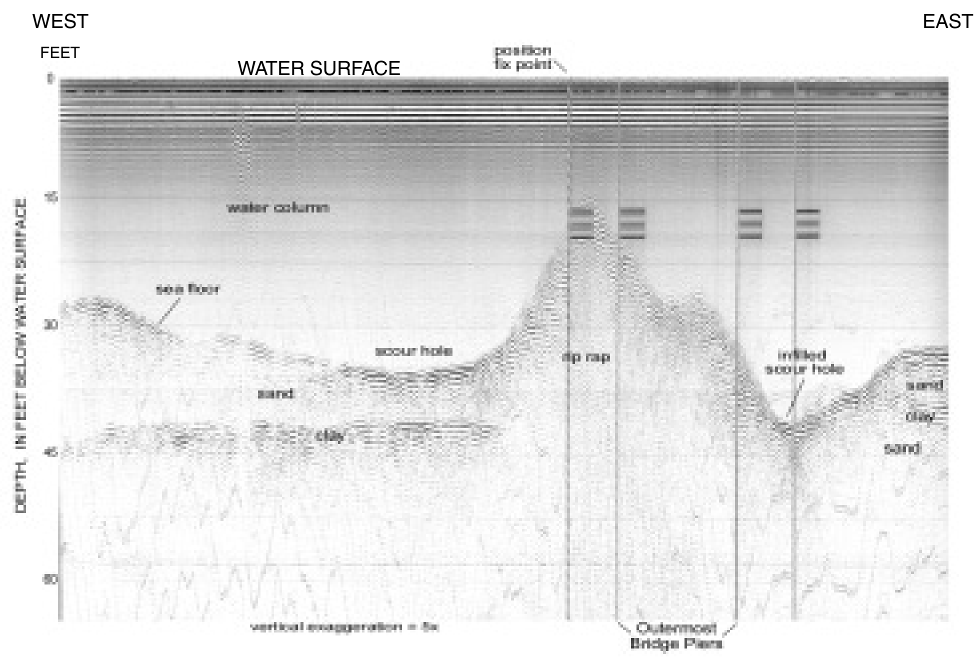


Figure 7. Interpreted high-frequency seismic-reflection profile between piers 6 and 7 at Sloop Channel Bridge, Nassau County, N.Y., July 1998. (Location is shown in fig. 1.)

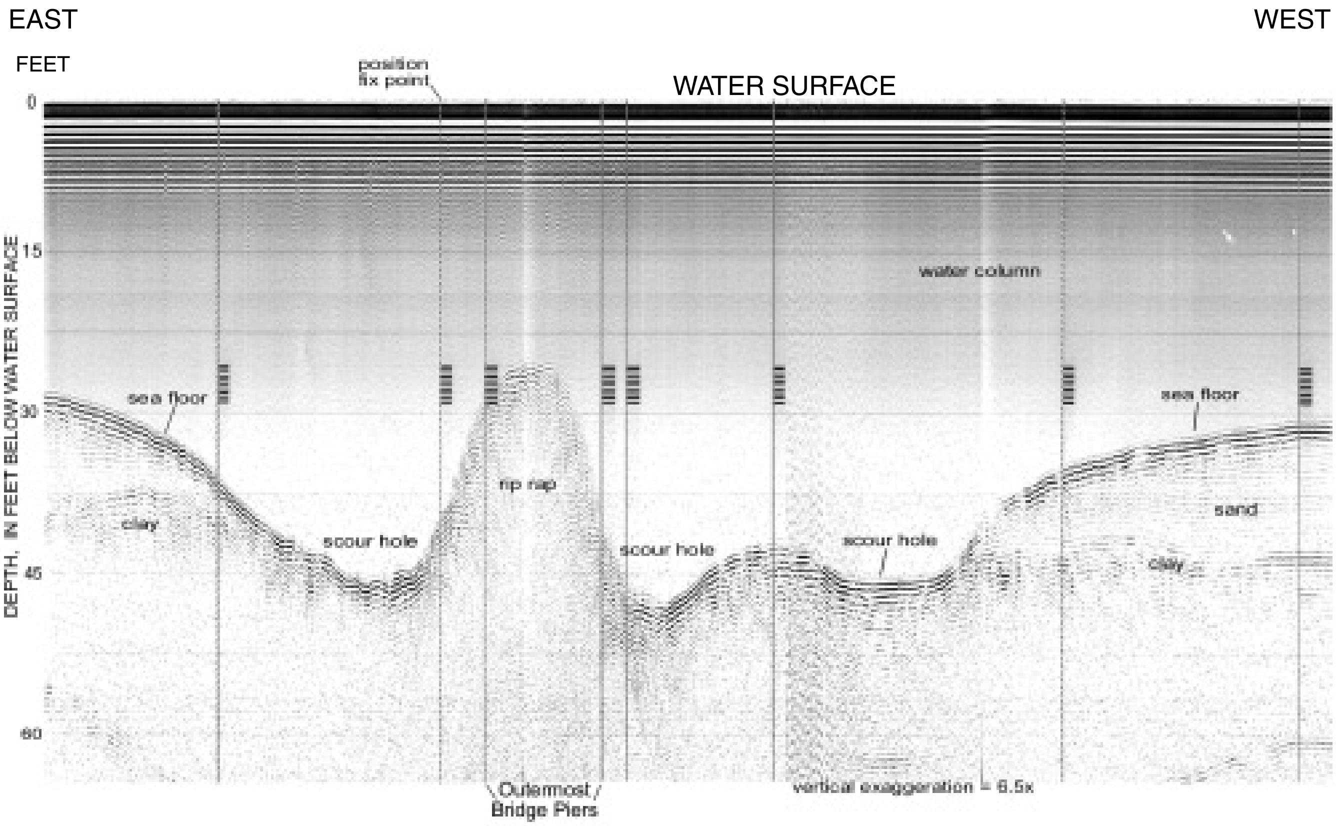
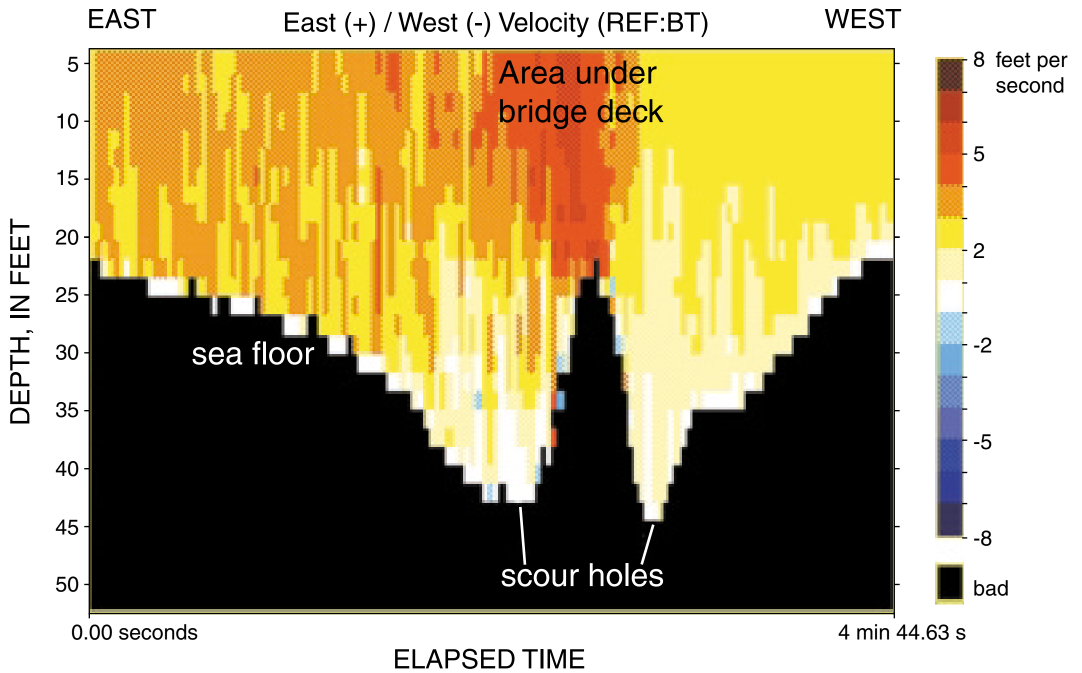


Figure 8. Interpreted high-frequency-seismic-reflection profile between piers 9 and 10 at Sloop Channel Bridge, Nassau County, N.Y., July 1998. (Location is shown in fig. 1.)

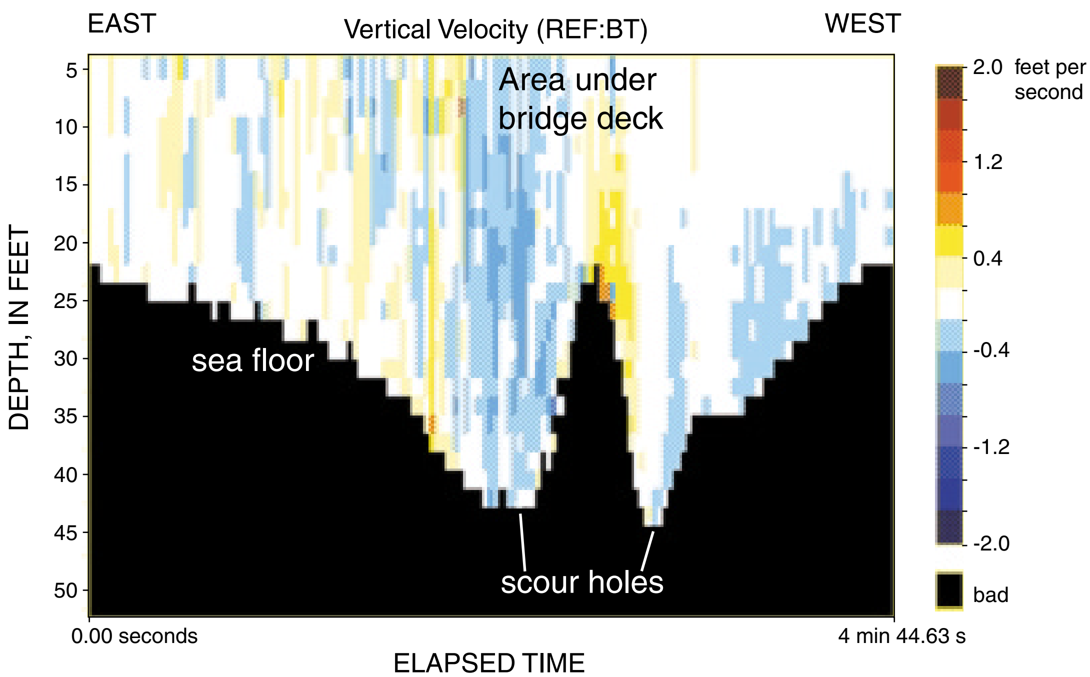
nearly parallel horizontal reflectors at the top of the sea floor, and extends to a depth of 49 ft below water surface, 4 ft deeper than could have been detected by fathometer alone. The western scour hole may contain even more sediment, in that the nearly parallel horizontal reflectors indicate sand and silt infill almost 5 ft below the sea-floor riprap; thus, the western scour hole extends to about 51 ft below water surface, or 5 ft deeper than could have been detected by narrow-beam fathometer alone. Beneath the sea floor is an assemblage of cross-bedded sands and clay horizons. Fine-sand cross beds can be seen on the easternmost and westernmost edges of the profile. Nearly parallel horizontal reflectors indicate sand and silt infill almost 5 ft below the sea-floor riprap; thus, the western scour hole extends to about 51 ft below water surface, or 5 ft deeper than could have been detected by narrow-beam fathometer alone. Beneath the sea floor is an assemblage of cross-bedded sands and clay horizons. Fine-sand cross beds can be seen on the easternmost and westernmost edges of the profile. Nearly parallel horizontal reflectors indicate a distinct clay horizon dipping from 38 to 43 ft below water surface; this horizon is continuous except where it has been truncated by the eastern and western scour holes.

Discharge Measurement

The USGS deployed an ADCP at Sloop Channel because of the difficulty and danger of conducting a conventional discharge measurement from the Sloop Channel Bridge. The ADCP measured flow velocities in three dimensions. Flow measurements were made during flood and ebb tides to obtain peak-flow



A. East - West Velocity



B. Vertical Velocity

Figure 9. Acoustic Doppler current profiler (ADCP) velocity profile between piers 9 and 10 during flood tide at Sloop Channel Bridge, Nassau County, N.Y.: A. East-west velocity. B. Vertical velocity. (Location is shown in fig. 1.)

values. Tidal elevation data from the USGS Point Lookout tide gage (fig. 1) were used to calculate high and low tides.

Peak flow under Sloop Channel Bridge over four ADCP profiles at flood tide on July 20, 1998, was 41,800 ft^3/s, and the corresponding value at ebb tide was 27,600 ft^3/s. ADCP data indicate that flow velocities increase sharply beneath the Sloop Channel Bridge. A typical ADCP east-west profile (fig. 9A) depicts velocity vectors during flood tide (eastward flow) between piers 9 and 10. The eastward velocity triples from about 2 ft/s west of the bridge to almost 6 ft/s beneath the bridge (fig. 9A), and the vertical velocity profile between piers 9 and 10 (fig. 9B) indicates a shift from almost no vertical flow west of the bridge to upward flow of 0.5 ft/s along the western slope of the riprap under the bridge. A downward velocity of 0.5 ft/s was measured on the east side slope of the riprap. ADCP velocity data between all piers indicate sharp increases in horizontal and vertical velocities beneath the bridge at both flood and ebb tides. These increases in flow velocities under the bridge are due to constricted flow caused by the bridge structure and riprap. The constricted flow through the 16 separate channels at flood and ebb tides creates a flumelike effect. The larger the number of bridge piers and amount of riprap, the smaller the cross-sectional areas between piers, and the greater the current velocity in and around the bridge structure. The increases in flow velocity, in turn, increase the bed-load capacity and the erosional (scour) capability.

Goose Creek Bridge

The Goose Creek Bridge, the middle in a series of three bridges connecting the Nassau County mainland to Jones Beach Island, connects Low Island to Green Island (fig. 1B) in South Oyster Bay. Narrow-beam fathometer and high-resolution seismic-reflection surveys were conducted at Goose Creek Bridge during July 1998. By this time, the NYSDOT had torn down the northern and southern approach ramps and replacing them with temporary steel decks. During this process, most of the original concrete piers were removed or partly broken away. The remaining piers were numbered 1 through 9, with 1 at the southern abutment, and 9 at the northern abutment to reference the locations of the survey tracklines to the bridge. This numbering scheme and the locations of selected survey transects are shown in figure 2.

Fathometer Survey

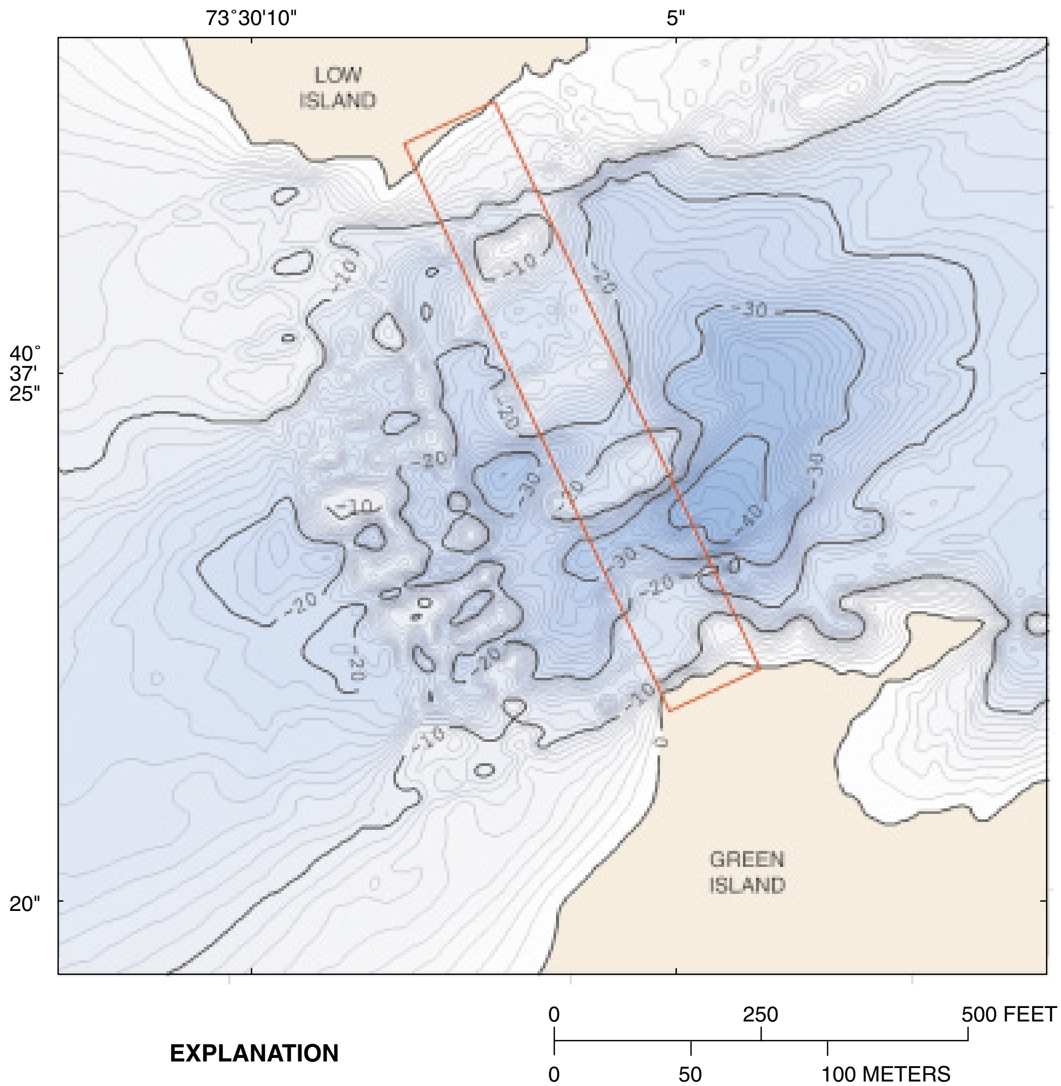
A bathymetric map of the channel bottom in the vicinity of the Goose Creek Bridge (fig. 7) was created from about 4,000 measurements made by a narrow-beam fathometer that provided depth readings at 0.5-second intervals. Depth values were automatically recorded and paired with continuous differentially corrected GPS locations, and the depth data were then contoured (fig. 10).

The primary scour feature at Goose Creek Bridge is a scour hole beneath the southern approach ramp to the center span; the depth of this hole ranges from 30 to 43 ft below sea level. This scour hole extends northward along the east side of the bridge and east of the center span to a depth of about 38 ft below sea level; beneath the center span its depth ranges from 28 to 22 ft below sea level. A comparison of the bathymetric map of Goose Creek with that of Sloop Channel (fig. 4) shows that the primary scour hole at Goose Creek is on the east side of the bridge, whereas the Sloop Channel Bridge has two main scour holes, one on either side, that range from 30 to 45 ft below sea level. A scour pattern similar to that at the Sloop Channel Bridge may have caused the undermining of piers at the Goose Creek Bridge. A possible lack of riprap in certain places beneath Goose Creek Bridge could have accelerated the scour-hole migration such that the eastern and western scour holes may have merged beneath the southern part of the bridge.

Seismic-Reflection Profiles

Seismic-reflection profiles of Goose Creek imaged the sediments beneath the sea floor between the centerspan and between piers 5 and 6, 2 and 3, and 1 and 2.

Centerspan.— A seismic-reflection profile obtained beneath the bridge centerspan (west to east) is shown in figure 11. The main feature is the large scour hole on the east side of the bridge deck (44 ft deep, as measured from the water surface at the time of the survey). This scour hole corresponds to the 38-ft-deep scour hole on the east side of the centerspan shown in the bathymetric map (fig.10). The apparent depth discrepancy reflects the conversion of the bathymetric data to sea level, whereas the seismic-



EXPLANATION

APPROXIMATE LOCATION OF BRIDGE

-10 LINE OF EQUAL SEA-FLOOR ELEVATION (Contour interval 1 foot. Datum is mean sea level.)

(coastline is approximate)

Figure 10. Bathymetric contour map of the sea floor at Goose Creek Bridge, Nassau County, N.Y., July 1998. (Location is shown in fig. 1.)

reflection data were obtained at high tide. Also, the seismic-reflection survey may have measured a different part of the scour hole than the fathometer. In addition to the scour hole, a horizontal high-amplitude reflection is visible to the west at about 27 ft below the water surface (fig. 11). This persistent reflection appears in nearly all of the profiles collected at both bridges and is interpreted as the top of a clay horizon. This marker horizon is truncated by the scour hole and appears again at the same elevation on the east side of the scour hole. Above this marker bed on the east side are sloped reflectors, which are interpreted as cross-bedded sand. Riprap beneath the bridge appears as a series of overlapping hyperbolic reflections that indicate point reflectors. Nearly parallel horizontal reflectors suggest infilling of the scour hole by 1 to 2 ft of fine-grained sediment.

Piers 5 and 6.— The seismic-reflection profile along a transect between piers 5 and 6, north of the

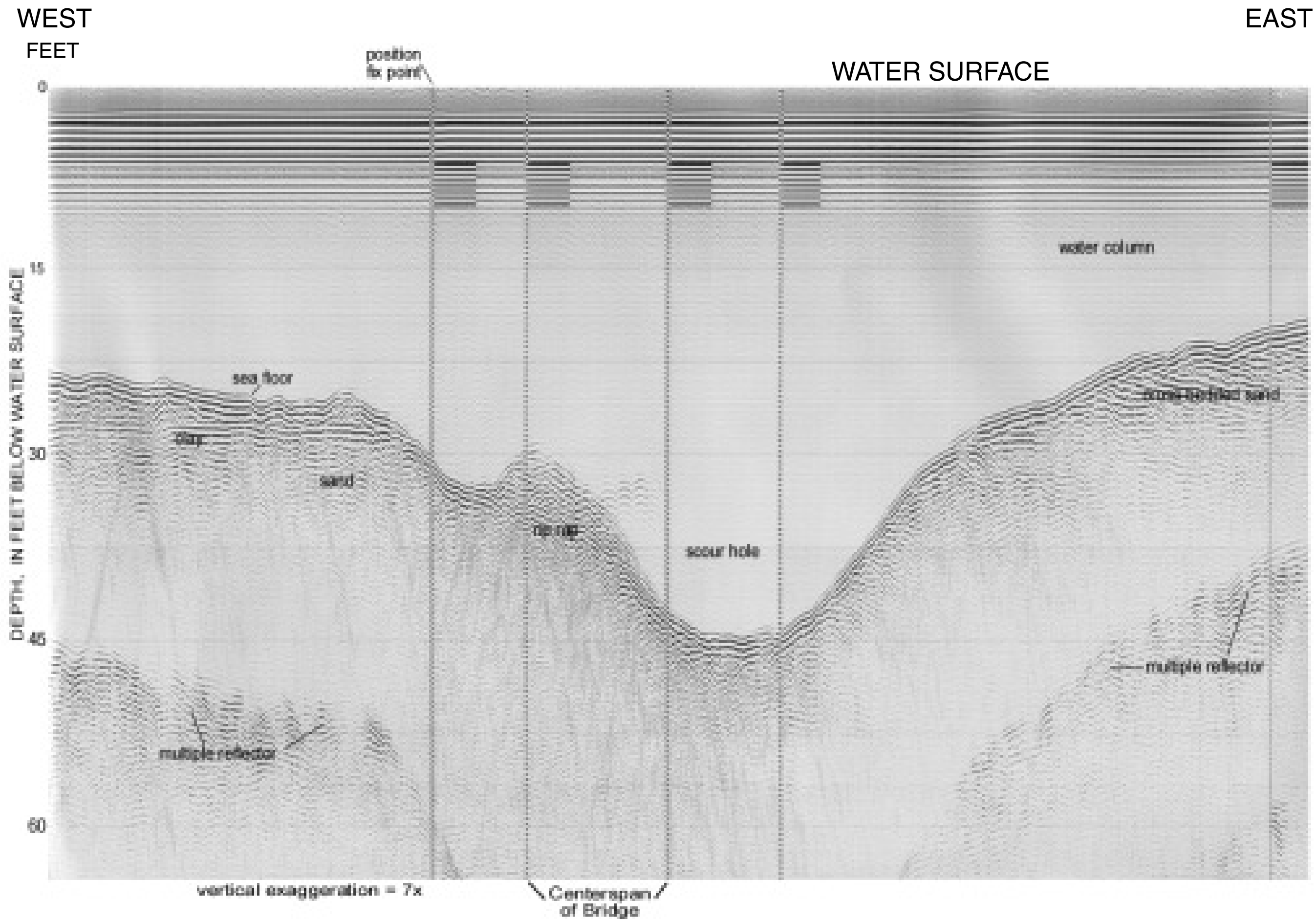


Figure 11. Interpreted high-frequency seismic-reflection profile between centerspans at Goose Creek Bridge, Nassau County, N.Y., July 1998. (Location is shown in fig. 1.)

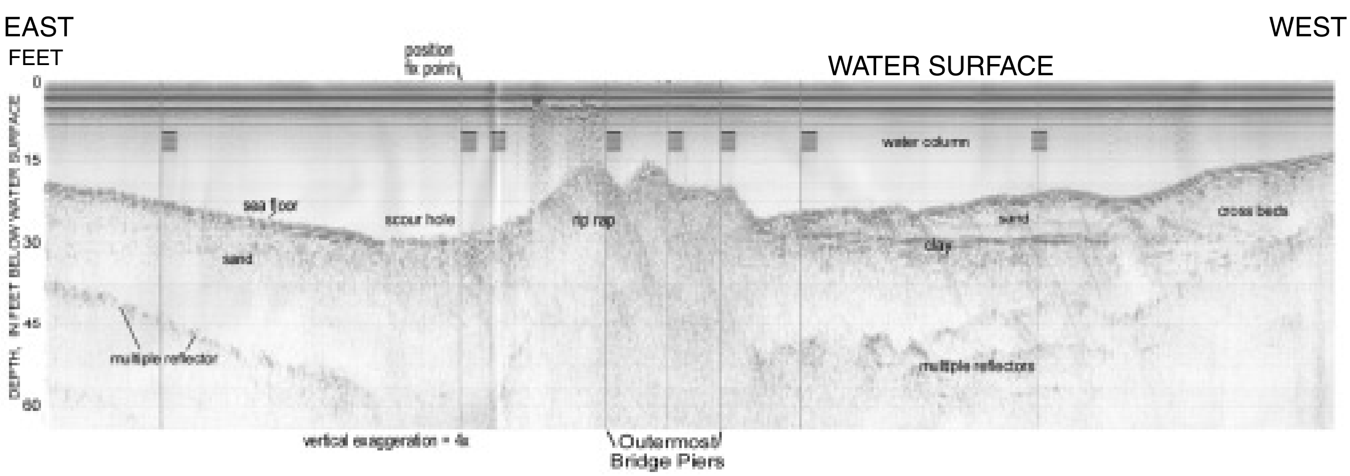


Figure 12. Interpreted high-frequency seismic-reflection profile between piers 5 and 6 at Goose Creek Bridge, Nassau County, N.Y., July 1998. (Location is shown in fig. 1.)

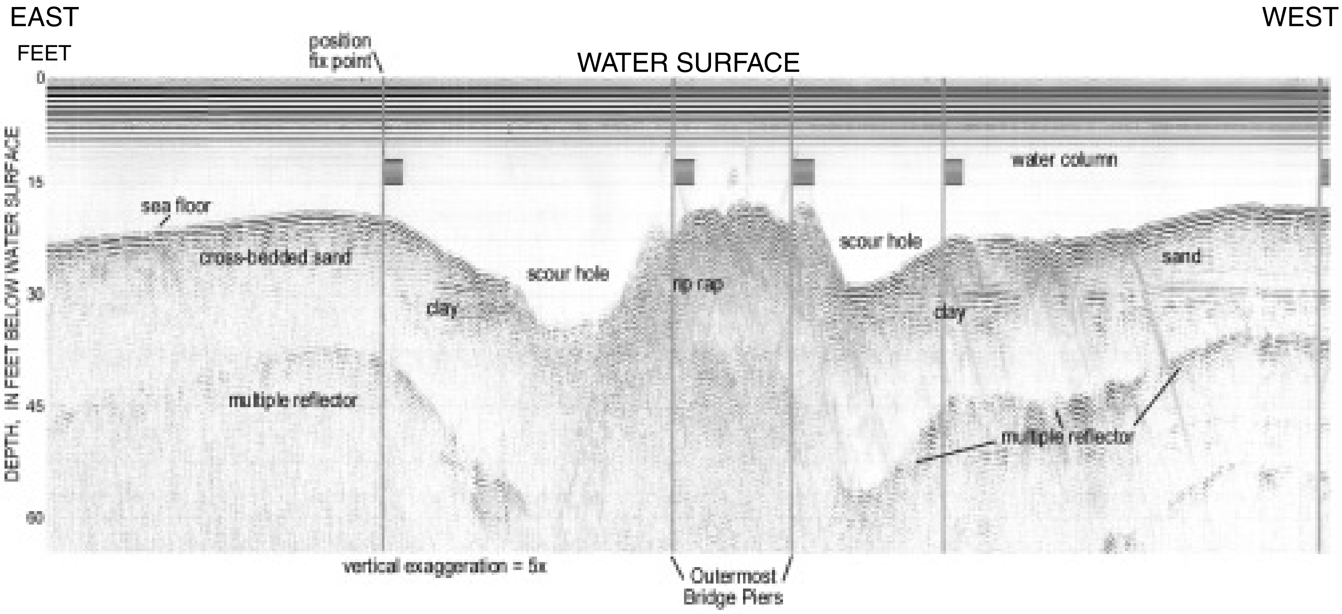


Figure 13. Interpreted high-frequency seismic-reflection profile between piers 2 and 3 at Goose Creek Bridge, Nassau County, N.Y., July 1998. (Location is shown in fig. 1.)

center span (fig. 12), depicts the shallow sedimentary material in the area, including the high-amplitude clay horizon 30 ft below the water surface. This reflector is clearly visible on the west side of the bridge in figure 12 but disappears halfway under the bridge as a result of signal attenuation and scattering by the riprap. High-amplitude chaotic reflections and hyperbolic reflections under the bridge indicate riprap. The broad scour hole on the east (left) side of the profile has eroded the overlying sand down to the top of the clay horizon. A shallower, but steep-walled, scour hole is seen on the west (right) side of the profile down to about 24 ft below the water surface.

Piers 2 and 3.— A transverse seismic-reflection profile between piers 2 and 3, south of the center span, is shown in figure 13. Again, the clay horion is clearly visible on the west side of the bridge at about 30 ft below the water surface but disappears under the bridge as a result of signal attenuation and scattering by overlying riprap. Hyperbolic reflections indicative of riprap are seen under the bridge. A scour hole, eroded down to the top of the clay horizon, is seen on the west side of the bridge. A second, deeper scour hole on the east side of the bridge reaches a depth of about 33 ft below the water surface. Reflections that indicate cross-bedded sand overlying the clay are seen on the east (left) and west (right) sides of the profile.

Piers 1 and 2.—A transverse seismic-reflection profile between piers 1 and 2 is shown in figure 14. This profile clearly shows the signal attenuation and scattering that is indicative of riprap. Here, the clay marker horizon (-30 ft) is indicated on the east and west sides of the bridge but disappears beneath the bridge as a result of signal attenuation and scattering by overlying riprap. As in the other Goose Creek Bridge profiles, the presence of riprap is confirmed not only by the signal attenuation but by the overlapping hyperbolic reflections indicative of point reflectors. Reflections from cross-bedded sand are seen overlying the marker bed on the east and west sides of the profile. Scour holes that are seen to either side of the bridge are eroded down to about 22 ft below the water

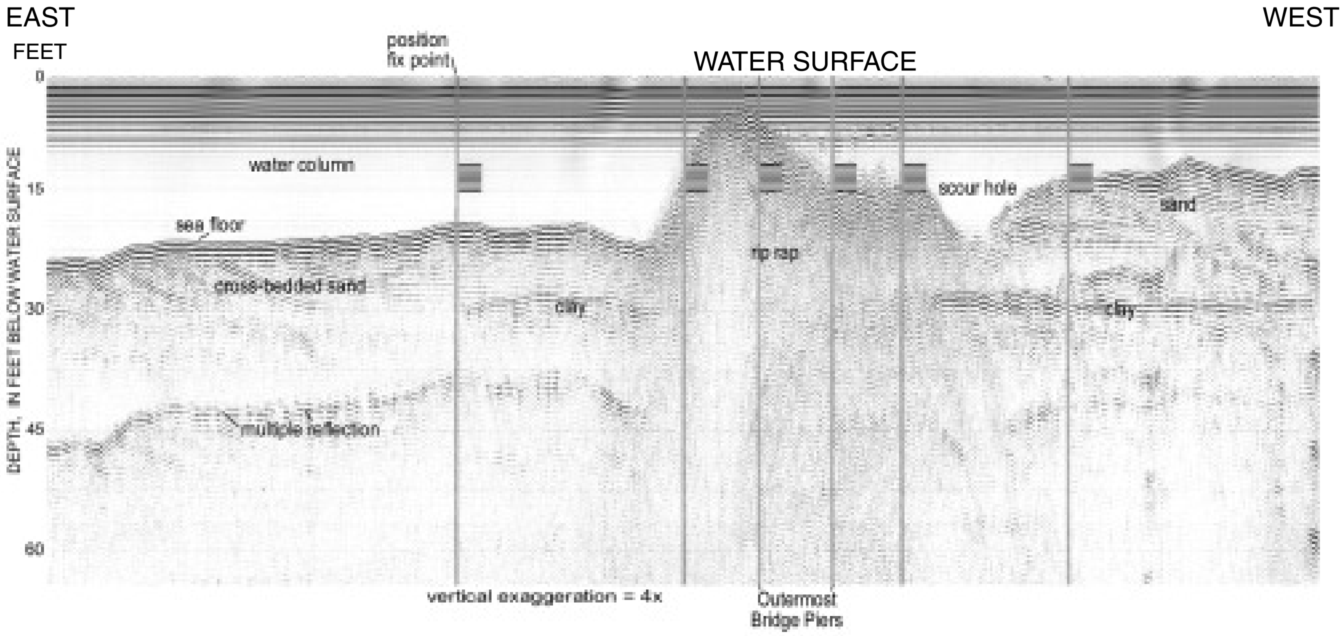


Figure 14. Interpreted high-frequency seismic-reflection profile between piers 1 and 2 at Goose Creek Bridge, Nassau County, N.Y., July 1998. (Location is shown in fig.1.)

surface. The seismic-reflection profile of the scour hole on the west side of the bridge shows possibly appreciable infilling by fine-grained sediment, 4 to 5 ft thick, which indicates that the scour-hole bottom may be 27 ft below the water surface—4 to 5 ft deeper than could have been seen by fathometer alone.

SUMMARY AND CONCLUSIONS

This study (1) produced bathymetric-surface maps of the area beneath and surrounding Goose Creek and Sloop Channel Bridges, (2) delineated the geologic characteristics of the sediment beneath the sea floor at these locations, (3) measured the three-dimensional flow characteristics of the tidal currents at Sloop Channel Bridge during July 1998, and (4) delineated the extent of tidal scouring and infilling of scour holes at both bridges during July 1998.

The multiple-technique geophysical surveys at both the bridges included a narrow-beam 200-khz research-grade fathometer, precision differential GPS, high-frequency seismic-reflection surveys, and ADCP measurement to produce high-resolution information on the extent and depth of tidal scour at both bridges. The fathometer surveys yielded bathymetric maps of the surface of the sea floor beneath and surrounding both bridges; these maps accurately depict the locations and depths of the scour holes associated with the bridges. The similarity of scour patterns at Sloop Channel Bridge to those at Goose Creek Bridge indicate the tidal scour at bridge structures may be a regional phenomenon in the coastal waters of Long Island. Several bridge piers were found to be extensively undermined by tidal scour during the July 1998 survey. This information was relayed immediately to the Federal Highway Administration and NYSDOT officials.

Analysis of the seismic-reflection profiles indicates many of the scour holes at Sloop Channel and Goose Creek bridges are infilled with 2 to 5 ft of sediment. The fathometer's inability to penetrate these deposits results in an underestimation of the true depth of bridge scour; thus, a geophysical survey was used to obtain sea-floor-surface information and data on the materials beneath the sea floor. The seismic-reflection surveys delineated the extent of riprap under both bridges from the pattern of reflections measured. In addition, several clay horizons were detected; the depths to the tops of these units and their thicknesses were calculated.

The three-dimensional current velocities measured by the ADCP at Sloop Channel Bridge provided accurate values of total discharge beneath Sloop Channel Bridge at flood and ebb tides. The vertical and horizontal velocities beneath the bridge indicate constricted flow regimes under the bridge. These constricted flow regimes are attributed to the decreased cross-sectional area created by the 17 rows of concrete piers and riprap. A reduction in the number of rows of piers and riprap would increase the individual cross-sectional area beneath the bridge and lower the horizontal current velocities, which in turn would reduce the bedload capacity of the water and slow the rate of scour.

The use of wide-beam fathometers, low-precision horizontal positioning equipment, and lack of depth measurements in previous studies have proved inadequate in determining the extent of bridge scour at bridges in the tidal embayments surrounding Long Island. The high-precision fathometer surveys and differential GPS, accurate to within 3 ft and combined with seismic-reflection surveys, produced more comprehensive and accurate data on the extent of tidal scour at bridge structures.

REFERENCES CITED

Bedingfield, L., and Murphy, V., 1987, Surveying for scour: Civil Engineering, v. 57, p. 67-69.

Brabets, T.P., 1995, Application of surface geophysical techniques in a study of geomorphology of the Lower Copper River, Alaska: U.S. Geological Survey Water-Resources Investigations Report 94-4165, 47 p.

Crumrine, M.D., 1991, Results of a reconnaissance bridge-scour study at selected sites in Oregon using surface-geophysical methods: U.S. Geological Survey Water-Resources Investigations Report 90-4199, 44 p.

Gorin, S.R., and Haeni, F.P., 1989, Use of surface-geophysical methods to assess riverbed scour at bridge piers: U.S. Geological Survey Water-Resources Investigations Report 88-4212, 33 p.

Haeni, F.P., 1986, Application of continuous seismic-reflection methods to hydrologic studies: Ground Water, v. 24, no. 1, p. 23-31.

_____ 1988, Evaluation of the continuous seismic-reflection method for determining the thickness and lithology of stratified drift in the glaciated northeast, in Randall, A.D., and Johnson, A.I. (eds.), Regional aquifer systems of the United States—the northeast glacial aquifers: American Water Resources Association Monograph 11, p. 63-82.

Haeni, F.P., and Gorin, S.R., 1989, Post-flood measurement of an infilled scour hole at the Bulkeley Bridge in Hartford, Connecticut, in Proceedings of the Bridge Scour Symposium: McLean, Va., Federal Highway Administration Report FHWA-RD-90-035, p. 147-174.

Haeni, F.P., and Placzek, Gary, 1991, Use of processed geophysical data to improve the delineation of infilled scour holes at bridge piers, in Expanded abstracts with biographies, SEG 61st Annual International Meeting, Houston, Texas, November 10-14, 1991: Houston, Texas, Society of Exploration Geophysicists, p. 549-552.

Morlock, S.E., 1996, Evaluation of acoustic doppler current profiler measurements of river discharge: U.S. Geological Survey Water-Resources Investigations Report 95-4218, 37 p.

Oberg, K.A., and Mueller, D.S., 1994, Recent applications of Acoustic Doppler Current Profilers, in Pugh, C.A. (ed.), Fundamentals and advancements in hydraulic measurements and experimentation, ASCE symposium, Buffalo, New York, August 1-5, 1994: Buffalo, N.Y., American Society of Civil Engineers, p. 341-350.

Placzek, Gary, and Haeni, F.P., 1995, Surface-geophysical techniques used to detect existing and infilled scour holes near bridge piers: U.S. Geological Survey Water-Resources Investigations Report 95-4009, 44 p.

Placzek, Gary, Haeni, F.P., and Trent, R.E., 1993, Use of geophysical data to assess scour development, *in* Hydraulic Engineering ‘93—National conference on engineering hydrology, San Francisco, July 15-30,1993, Proceedings: American Society of Civil Engineers, p. 2051-2056.

Reynolds, R.J. and Williams, J.H., 1988, Continuous marine seismic-reflection survey of glacial deposits along the Susquehanna, Chemung, and Chenango Rivers, south-central New York and north-central Pennsylvania, *in* Randall, A.D., and Johnson, A.I. (eds.), Regional aquifer systems of the United States—the northeast glacial aquifers: American Water Resources Association Monograph 11, p. 83-103.

Robinson, E.S., and Çoruh, Cahit, 1988, Basic exploration geophysics: New York, John Wiley, 562 p.