

# Laboratory Tests of Scour-Monitoring Devices

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The recent failure of bridge pier footings and foundations because of scour and erosive processes has resulted in the need to monitor the maximum scour depths. During the past 5 years, more than 30 types of device for measuring scour have been developed for field use. Many of these devices have not been fully tested either in laboratory or field situations. A laboratory testing program was conducted to evaluate the effectiveness and practicability of several scour-monitoring devices. A series of flume tests was performed evaluate driven and falling rod model devices. Sonar measurement devices were tested in a sump and visual accumulation tube to analyze the affects of transducer transmission angle, transducer mounting angle, transducer submergence depth, transducer mounting distance from the pier, and temperature on accuracy and reliability. It was determined that vertically supported falling rods and the scuba mouse were practicable devices when mounted in front of the pier. The sonar device has a high potential for field application, although it is sensitive to water temperature, mounting angle, and transducer placement location in front of the pier.

The recent failure of bridge pier footings and foundations because of long-term degradation, local scour at piers and abutments, and lateral stream migration has highlighted the need to develop a means of monitoring scour depths at and near pier foundations and abutments. Nearly 86 percent of all bridges in the United States span a water body, so durable, accurate, and cost-effective monitoring devices are needed to protect the health and safety of the highway user. Furthermore, because many scour processes are cyclic, accurate measurements of scour during storm events are needed.

During the past 5 years, more than 30 types of scour measurement instruments have been conceptually proposed, planned, or fabricated. Fewer than 20 of these devices have been developed and refined for field use. These scour-monitoring devices include sounding weights, sounding rods, driven rods, ultrasonic sounders, sonar, conductance probes, optical sand-surface meters, and the scuba mouse. Although prototypes of each of these devices are in development or use, many have not been fully tested under either laboratory or field situations.

In an attempt to evaluate the effectiveness of some of the scour-monitoring concepts, a program was formulated to test scale-model and near-prototype scour-monitoring devices. The devices tested and reported in this document were selected through an extensive analysis performed by Resource Con-

sultants, Inc., within the scope of work negotiated in a contract with NCHRP. The selection of devices for measuring scour was based on hydraulic factors, mounting requirements, ability to measure scour depth to  $\pm 1.0$  ft, long-term reliability, and cost minimization. It should be recognized that one instrument may not be applicable to all bridges or stream conditions.

## OBJECTIVES

The objectives of the laboratory test program are to

1. Test and evaluate a scale model(s) or prototype measurement instrument or device considered practicable for field consideration.
2. Provide recommended refinements for the redesign or improvement of those instruments that were deemed practicable as a result of the initial testing.
3. Recommend those instruments that appear most practicable for near-prototype and field testing.

This paper will present a description of the laboratory testing program and test results on selected instruments and devices considered practicable.

## TEST FACILITIES

The testing program was conducted in the Hydraulics Laboratory at the Engineering Research Center of Colorado State University. The program used three permanent facilities in the laboratory.

### Recirculating Flume

Scale-model instruments were tested in an existing recirculating steel flume. The flume—200 ft long, 8 ft wide, and 4 ft deep—can be adjusted to vary the slope from zero to nearly 3 percent. The flume has a discharge capacity of approximately 100 ft<sup>3</sup>/sec. Flow through the flume can exceed 10 ft/sec.

The interior of the flume was segmented into three sections: a flow development section, a test section, and a tailwater control and material recovery section. The flow development section extended from the flume headbox and diffuser downstream approximately 100 ft. The test section abutted to the

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flow development section and extended downstream approximately 60 ft. A model pier was installed into the test section, simulating placement into a stream channel composed of erodible material. The remaining 40 ft of the flume served as a bed material recovery basin and tailwater control. The flume slope was leveled at approximately 0.5 percent.

The pier is a 1:15 (model:prototype) Froude scale model of the prefailure pier of the New York State Thruway bridge over Schoharie Creek. The model pier is 65.8 in. long and 15.1 in. wide, the footing thickness is 4.0 in., and the pier height is 31.9 in., as illustrated in Figure 1. The pier was mounted such that the base of the footing was elevated approximately 1 ft above the flume bottom and situated parallel to the flume sidewalls.

The bed material was composed of two noncohesive sands with median grain sizes of approximately 2.3 and 4.0 mm. Both bed materials have a coefficient of uniformity of approximately 1.9. The bed materials were loosely placed in the flume to an elevation of 8 in. above the top of the footing.

A driven and sounding rod was used to simulate pier monitoring devices. A circular steel rod 56 in. long and 0.77 in. in diameter was used in all the tests.

### Sonar Test Apparatus for Depth

Two sonar devices were tested in the laboratory sump for accuracy and reliability. A prefabricated scour hole was constructed of wood and metal materials. The scour hole was designed for placement at the bottom of the sump such that the back edge (high side) would fit adjacent to the sump wall. The sump is 8 ft deep with a water level that varies from 6 to 7.5 ft deep.

Once the scour hole was placed into the sump and the sump was filled, an angle iron was installed directly above the scour hole such that the angle iron aligned along the centerline of the scour hole. A point gauge with transducer mounting bracket

was installed on the angle iron. The mounting bracket was pre-fabricated allowing the transducer face to rotate 0 to 30 degrees. The sonar device(s) were installed into the mounting bracket located at the end of the point gauge. The test apparatus allowed the user to situate the transducer at any depth into the sump and locate the transducer at any position over the scour hole center line.

The two sonar devices tested in the sump were the Eagle Corp. Sonar Model Z-9500 with a transmission angle of 8 degrees and the Lawrence Corp. sonar with a transmission angle of 20 degrees. Both devices are commercially available.

### Sonar Test Apparatus for Temperature

A Plexiglas visual accumulation tube (VA) was used to determine how temperature may affect the accuracy of the Eagle Corp. Z-9500 sonar instrument. The VA tube is 10 ft high and 16.375 in. in diameter (OD); its walls are 0.25 in. thick. A point gauge with mounting bracket was suspended from the top of the tube. The sonar transducer was installed into the bracket at the base of the point gauge. Water was placed into the tube to a depth of approximately 6.8 ft. The water temperature was varied by adding warmer water or ice as required. A mercury thermometer accurate to  $\pm 1^\circ\text{F}$  was used to monitor the fluid temperature. A point gauge,  $\pm 0.05$  ft, was used to monitor the water depth.

## TEST PROGRAM

The test program was conducted in three phases, each phase was composed of a series of tests oriented toward accomplishing one of the stated objectives. Each test phase will be summarized.

### Phase I

The objective of the Phase I tests was to evaluate the general applicability of using vertically supported and near-vertical sounding rods in simulated alluvial bed channels. A series of 10 tests was conducted in the recirculating flume. The test configurations were analyzed using two bed materials. The first set of six test configurations used a 4.0-mm bed material and included a base run without monitoring device, a vertically supported falling rod placed immediately upstream of the pier foundation, a vertically supported driven rod placed immediately upstream of the pier foundation with simulated scuba mouse, a vertically supported falling rod placed through the footing, a vertically supported driven rod placed through the footing, and a vertically supported falling rod with expanded base plate placed immediately upstream of the pier foundation. The second set of four test configurations used a 2.3-mm bed material and included a base run without monitoring device, a vertically supported falling rod with enlarged base plate placed immediately upstream of the pier foundation, a vertically supported driven rod with scuba mouse placed immediately upstream of the pier foundation, and an angled (45 degrees) falling rod with base plate.

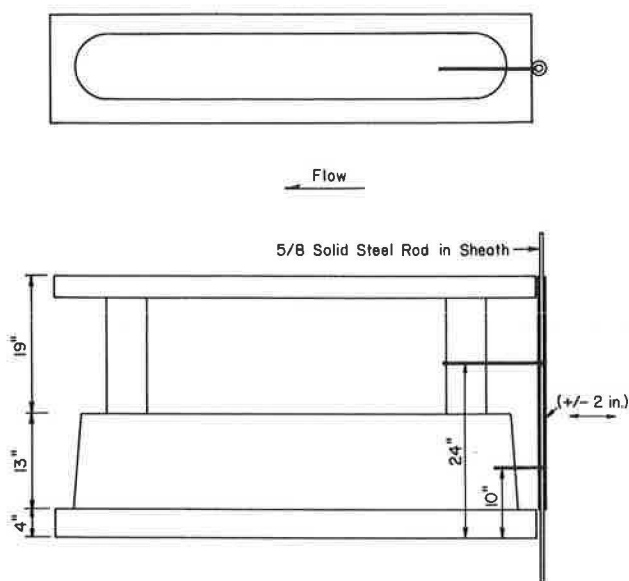


FIGURE 1 Plan (top) and profile (bottom) of model pier.

Each of the 10 tests was conducted in a similar fashion. After placement of the pier, the test section was filled (approximately 2 ft) with the appropriate bed material. The bed was leveled. Flow was initiated and the flume was slowly filled until the water depth was approximately 0.8 ft deep. The discharge was adjusted until the flow velocity was approximately 2.0 ft/sec. During the run, velocity measurements were obtained at 0.6 times the flow depth measured from the water surface. The run extended for approximately 2 hr. The flow was discontinued and the bed was contoured. The discharge was reinitiated to a flow depth of approximately 1.2 ft and a velocity of approximately 3.0 ft/sec. After a 2-hr test duration and collection of the velocity data, the flume was again shut down and the bed contoured. The discharge was again re-established at an approximate depth of 1.5 ft and an approximate velocity of 4.0 ft/sec. Upon completion of the run, the bed was contoured and photographically documented. When monitoring devices were installed, data were also collected pertaining to the device scour-depth measurements. Figure 2 presents the point gauge and velocity measurement locations in the test section.

## Phase II

The objective of Phase II was to evaluate the accuracy and reliability of using a sonar monitoring device under a spectrum of operating conditions. Two sonar transducers were tested previously under similar operating conditions. Test parameters included the transducer's mounting angle, mounting distance from the simulated pier (wall), and submergence depth. Transducer mounting angles varied from 0 to 25 degrees, and transducer submergence ranged from 0 to 2.5 ft below the water surface. The transducer was situated adjacent to the pier at Station 0. The transducer was extended from the simulated pier 0.0 to 5.0 ft in intervals of 0.5 ft. A total of 360 data points were collected.

The test procedure was similar for each test series. Once the appropriate transducer was installed into the point gauge mounting bracket and adjusted to the appropriate mounting

angle, the sonar device was turned to the on position and calibrated. The transducer face was then submerged and placed adjacent to the simulated pier directly above the centerline of the simulated scour hole. The sonar was allowed to stabilize, and a depth measurement was recorded. The transducer was moved from the pier 0.5 ft along the simulated scour hole centerline, and the sonar measurement was again recorded. Transducer measurements were systematically taken until the transducer extended 5 ft from the simulated pier along the centerline of the scour hole. The transducer was then lowered into the sump, and the sonar measurements were repeated. When all the submergence depths and distance depths were obtained, the entire process was repeated for each of the different mounting angles. The second transducer was installed and a limited data set was recorded.

## Phase III

The objective of the Phase III testing program was to determine whether the accuracy of the sonar device is affected by a change in the fluid temperature. Only the Eagle Corp. Model Z-9500 device was tested in this phase. A series of 24 test measurements was obtained. The test parameters included the water temperature and the submergence of the transducer. The water temperature varied from 42°F to 96°F and the transducer submergence varied from 0.0 to 1.5 ft below the water surface.

The test procedure was similar for all sequential measurements. Warm water was initially placed into the VA tube. The transducer was installed into the mounting bracket (0-degree mounting angle) and placed into the VA tube with the transducer face just below the water surface. The sonar device was turned to the "on" position, and the transducer was calibrated. After the water in the tube was stirred and the water temperature measured, the device was allowed to stabilize and a depth measurement was recorded. Then the transducer was lowered into the tube to the appropriate submergence depth and another measurement was recorded. Once all the submergence-related measurements were completed, water was drained from the tube and cooler water was added, thereby lowering the reservoir water temperature. When the temperature reached the desired level, the sonar device was again tested. This process was repeated for each of the temperatures in the test series.

## TEST RESULTS

The results of the testing program will be presented in three sections: pier monitoring devices, accuracy of sonar devices, and temperature affects on sonar. Quantitative and qualitative results will be presented.

### Pier Monitoring Devices

The pier monitoring devices refer to the vertically supported and near-vertical sounding rods. Ten test series were conducted with the pier monitoring devices in the recirculating flume.

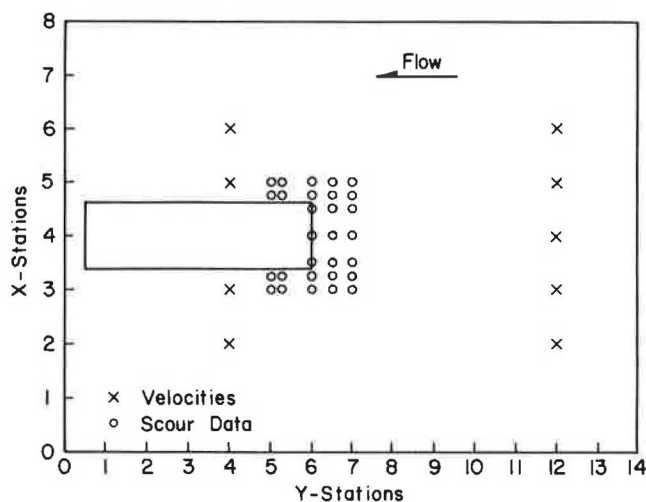


FIGURE 2 Data collection locations in flume test sections.

The initial test series conducted was with the pier installed in the 4.0-mm bed material without a monitoring device. Velocities of approximately 2, 3, and 4 ft/sec were routed through the channel; the resulting scour depths were measured and recorded. Each velocity run extended for 2 hr. Figure 3 depicts the scour hole after 6 hr of testing. It is observed that the maximum depth of scour occurred directly beneath the footing along the leading edge. Table 1 presents a summary of the approximate flow rates, velocities, and maximum scour depths (point gauge) observed. The base test served as a standard by which the remaining tests with monitoring devices could be compared.

The second test series simulated a vertically supported falling rod installed immediately upstream of the pier footing as shown in Figure 4. The foot of the rod was placed adjacent to the initial bed elevation. The rod measurement was taken at the end of each test run and was compared to the actual maximum depth of scour. It was observed that the rod drove itself into the bed, resulting in a maximum depth of scour measurement greater than the actual observed depth. It is speculated that the energy imparted into the device from the flow vibrated the rod to a level at which the bed material



FIGURE 3 Scour hole observed without monitoring device.

TABLE 1 SUMMARY OF FLUME TESTING PROGRAM

8' FLUME TESTING SUMMARY						
Test No.	Configuration	Flow Rate (cfs)	Flow Depth (ft)	Approach Velocity (fps)	$d_{50}$ (mm)	Maximum Scour Depth (ft)
1A	No Device - Base Run	15	0.8	2.11	4.0	0.17
1B	No Device - Base Run	28	1.2	2.98	4.0	0.60
1C	No Device - Base Run	45	1.5	3.90	4.0	0.68
2A	Falling Rod - front of footing	15	0.8	2.16	4.0	0.17
2B	Falling Rod - front of footing	28	1.2	2.92	4.0	0.57
2C	Falling Rod - front of footing	45	1.5	3.84	4.0	0.62
3A	Driven Rod - front of footing w/ scuba mouse	15	0.8	2.07	4.0	0.23
3B	Driven Rod - front of footing w/ scuba mouse	28	1.2	3.13	4.0	0.72
3C	Driven Rod - front of footing w/ scuba mouse	45	0.8	3.96	4.0	0.73
4A	Falling Rod - through footing	15	0.8	2.38	4.0	0.47
4B	Falling Rod - through footing	28	1.2	3.11	4.0	0.70
4C	Falling Rod - through footing	45	1.5	3.97	4.0	0.76
5A	Driven Rod - through footing	15	0.8	2.06	4.0	0.20
5B	Driven Rod - through footing	28	1.2	3.17	4.0	0.56
5C	Driven Rod - through footing	45	1.5	3.74	4.0	0.56

(continued on next page)

TABLE 1 (continued)

Test No.	Configuration	Flow Rate (cfs)	Flow Depth (ft)	Approach Velocity (fps)	d <sub>50</sub> (mm)	Maximum Scour Depth (ft)
6A	Falling Rod - front of footing with base plate	15	0.8	2.09	4.0	0.17
6B	Falling Rod - front of footing with base plate	28	1.2	3.13	4.0	0.54
6C	Falling Rod - front of footing with base plate	45	1.5	3.93	4.0	0.57
7A	Falling Rod - front of footing with base plate	15	0.8	2.20	2.3	0.42
7B	Falling Rod - front of footing with base plate	25	1.2	2.57	2.3	0.45
7C	Falling Rod - front of footing with base plate	35	1.4	3.51	2.3	0.67
8A	No Device - base run	15	0.8	2.30	2.3	0.34
8B	No Device - base run	25	1.2	2.51	2.3	0.53
8C	No Device - base run	35	1.4	3.49	2.3	0.53
9A	Driven Rod - front of footing w/ scuba mouse	15	0.8	2.27	2.3	0.37
9B	Driven Rod - front of footing w/ scuba mouse	25	1.2	2.50	2.3	0.45
9C	Driven Rod - front of footing w/ scuba mouse	35	1.4	3.10	2.3	0.62
10A	Falling Angled Rod w/ Base Plate	15	0.8	2.24	2.3	0.47
10B	Falling Angled Rod w/ Base Plate	25	1.2	2.65	2.3	0.67
10C	Falling Angled Rod w/ Base Plate	35	1.4	3.09	2.3	0.69

could firmly support the weight of the rod. The rod was again observed to drive itself into the bed during the 2.0- and 4.0-ft/sec velocity runs. The rod provided a final maximum scour depth of 50 percent greater than the observed measurement. Although the device has merit for further testing, the device should be evaluated for the applicable bed materials in which the device can be confidently used.

In the third test series, a simulated scuba mouse was placed on a vertically supported driven rod. The device is a weighted ring that is free to fall along a guide rod. Conceptually, the ring will remain adjacent to the bed surface as the material erodes near the pier. Figure 5 illustrates the device in the scour hole after the 4.0-ft/sec test run. During the test series, it was observed that the device, as fabricated, tended to bind on the rod because of fine sands. Submergence of the device could bind the ring in place. It is speculated that with the appropriate design, that is, segmenting the ring or leaving adequate clearance between ring and rod, the device has merit for near-prototype testing.

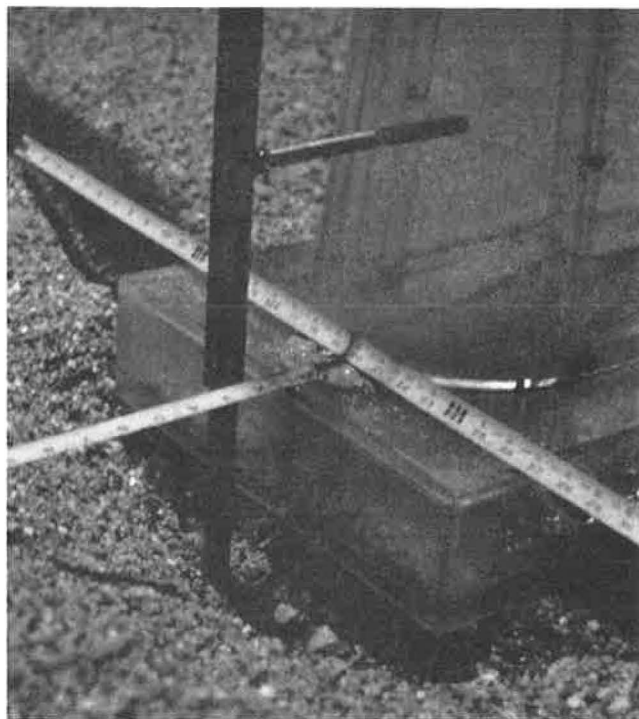
A vertically supported falling rod was installed through the pier footing, as shown in Figure 6, and tested for the three flow conditions. The base of the rod was situated adjacent to the bed directly below the footing. In the initial test flow condition, the scour-hole depth did not extend below the base

of the footing, thereby the device did not function. During the second flow condition, the scour hole extended beneath the footing. However, the rod was bound in the footing because of sands and fines that were sucked into the guide channel of the footer. In the third test run, the rod vibrated loose but again became jammed short of the actual scour-hole depth. The use of a vertically supported falling rod installed through the pier footing is not recommended for further testing. The rod tends to bind in the footing channel, it does not measure the maximum depth of scour, and it is considered difficult to retrofit.

A vertically supported driven rod was installed through the pier footing, similarly to the fourth test series. The test was performed to determine the influence of the rod on the maximum depth of scour. The rod did not increase the maximum depth of scour. The device is difficult to maintain and does not measure the maximum depth of scour. The driven rod through the footer is not recommended for further testing.

The sixth test series incorporated the same vertically supported falling device used in the second test series except that a base plate was installed at the bottom of the rod. The base plate diameter was three times the rod diameter. Contrary to the second test series, the rod no longer vibrated into the bed. In fact, the base plate stabilized the bed material under





**FIGURE 4** Vertically supported falling rod after testing.

the plate, which resulted in slightly shallower scour holes than the point gauge. However, the modified rod showed promise for use in alluvial bed materials because the weight of the rod is spread over a larger area. It is recommended that the vertically supported falling rod with enlarged base plate be tested further.

The bed material, median grain size of 2.3 mm, was placed into the flume. The seventh test series was then conducted in which the vertically supported falling rod with base plate was tested under similar conditions to Test Series 6. The device measured the maximum depth of scour within 0.07 ft of the observed depth, which is the most accurate of all the pier monitoring devices tested. The results are similar to those



**FIGURE 5** Scuba mouse in scour hole after testing.



**FIGURE 6** Vertically supported falling rod installed through pier footing.

recorded in Test Series 6. The device is recommended for further evaluation.

Test Series 8 served as a base run (no device) for the 2.3-mm bed material. The maximum scour depths are presented in Table 1.

The scuba mouse device used in Test Series 3 was again tested in Test Series 9. The ring was modified by increasing the clearance between the ring and the driven rod. The scuba mouse device performed very well—it did not bind on the rod. The large surface area of the ring prevented the device from being driven into the bed. The scuba mouse is recommended for further testing at the near-prototype scale.

The 10th test series evaluated the concept of using a falling rod with base plate installed at an angle. The device was placed at a 45-degree angle from the horizontal with the rod aligned parallel with the pier center line. The rod with base plate fell upstream of the pier into the direction of flow as shown in Figure 7. Although the device functioned well during the testing program (similar to the vertically supported falling rod with base plate), the rod base slides away from the location of the maximum depth of scour. The device is not recommended for further testing if configured as presented.



**FIGURE 7** Sounding rod with base plate installed at 45 degrees from horizontal.

In addition to the results pertaining to the practicality of the proposed scour-monitoring devices, the investigators were concerned about how the presence of a device affects the maximum depth of scour. A comparison of the maximum scour depths versus the Froude number ( $V/\sqrt{gd}$ ) is presented in Figure 8 for Test Series 1 through 6 (4.0-mm bed material). It is observed in Figure 8 that the maximum depth of scour is similar for all test conditions. Apparently, the presence of the monitoring device does not significantly or consistently affect the maximum depth of scour. As the ratio of the rod diameter to pier width decreases, the effect of the device on enhancing scour will diminish.

### Accuracy of Sonar Devices

The sonar device test program evaluated the accuracy of two sonar devices (8- and 20-degree transmission angles). The test parameters included the transducer mounting angle, the distance that the transducer is installed upstream of the pier, and the submergence depth of the transducer. A summary of the differences between sonar and point gauge measurements is given in Tables 2 and 3. The test series A, B, C, D, E, and F represent transducer mounting angles of 0, 5, 10, 15, 20 and 25 degrees, respectively. The entire test program was conducted with the sump water temperature ranging from 50°F to 54°F. The sump water was tranquil.

The sonar devices were evaluated for accuracy as a function of the transducer submergence. The transducers were submerged from 0.0 to 2.5 ft beneath the water surface and were tested directly above the simulated scour hole. The results indicate that the degree of submergence, or distance between transducer and scour hole, directly influences the accuracy of the device in shallow waters. It is observed in Table 2 that as the distance from scour hole to transducer (8-degree device) extended from 3.5 to 6.5 ft, the difference between sonar device and point gauge measurements increased as much as 28 to 152 percent. The average measurement differences appear to become a constant as the water depth exceeds 6.5 ft. Therefore, for a fixed or relatively fixed transducer mounting

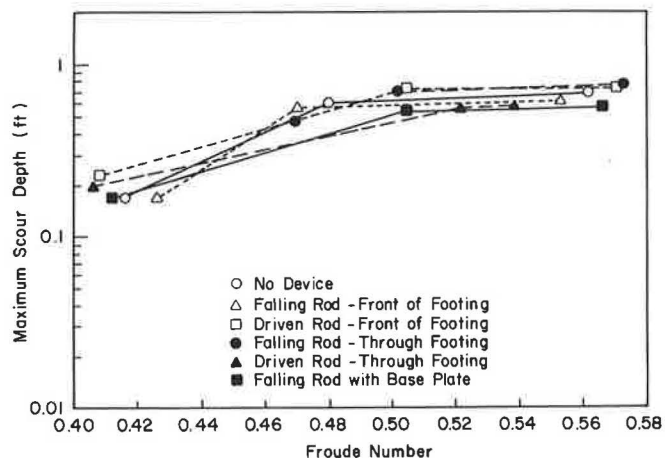


FIGURE 8 Maximum scour depth versus Froude number for Tests 1–6.

TABLE 2 DATA SUMMARY OF SONAR TEST INDEPENDENT OF DISTANCE FROM PIER (8-DEGREE TRANSDUCER)

Test			
Series	Average Differential (ft)	Maximum Differential (ft)	Station
Number			
A			
1	0.63	2.20	0.50
2	0.33	0.60	1.00
3	0.32	0.60	1.00
4	0.32	0.75	2.50
5	0.27	0.60	1.00
6	0.25	0.50	0.50
B			
1	0.88	2.70	0.00
2	0.83	2.70	0.00
3	0.53	1.00	0.00,0.50
4	0.46	1.00	0.50
5	0.42	0.90	0.50
6	0.42	0.90	0.50
C			
1	0.84	1.90	0.00
2	0.93	2.00	0.00
3	0.85	2.10	0.00
4	0.66	2.10	0.00
5	0.54	0.95	4.00
6	0.42	0.95	4.00
D			
1	1.12	2.40	0.00
2	1.14	2.00	0.00
3	0.95	2.00	0.00
4	0.97	2.10	0.00
5	0.92	1.80	0.00
6	0.87	1.90	0.00
E			
1	1.18	2.50	0.00
2	1.16	2.50	0.00
3	1.13	2.20	0.00,0.50
4	1.01	2.10	0.00
5	0.99	2.00	0.00,0.50
6	0.96	1.90	0.00
F			
1	1.35	2.70	0.00
2	1.38	2.80	0.00
3	1.25	2.60	0.00
4	1.26	2.50	0.00
5	1.16	2.40	0.00
6	1.05	2.30	0.00

TABLE 3 DATA SUMMARY OF SONAR TEST, INDEPENDENT OF DISTANCE FROM PIER (20-DEGREE TRANSDUCER)

Test			
Series			
Number	Average Differential (ft)	Maximum Differential (ft)	Station
A			
1	0.83	2.05	0.00
B			
1	0.71	1.85	0.00
C			
1	0.70	1.85	0.00

location in water 6.5 ft deep or greater, the submergence has little effect on the accuracy of a high-quality sonar device.

An analysis was conducted to determine the pier influence on the accuracy of the sonar device. The sonar transducer was tested as a function of the distance from the pier. The stationing in Tables 2 and 3 refers to the distance, in feet, the transducer was placed upstream of the pier centerline. The accuracy of the sonar device is determined as the difference between sonar and point gauge measurements. The smaller the difference in measurements, the greater the accuracy. The data indicate that the maximum difference, or error, occurs when the transducer is mounted within 1 ft of the pier. Apparently, both the 8- and 20-degree transducers signal reflects from the pier thereby interfering with the instruments ability to measure accurately the depth of the scour hole. The average difference in sonar and point gauge measurements decreases as the distance between pier and transducer increases. The measurement differences become constant at approximately 1.5 ft from the pier. On the basis of the laboratory test results presented, it is recommended that the sonar transducer not be placed within 1.5 ft of the pier.

The data were analyzed to determine the effect of the transducer mounting angle on the accuracy of the sonar device. The data indicate that when the transducer is located 1.5 ft from the pier, the average difference between sonar and point gauge measurements increases as the mounting angle increases. For example, it is observed in Figure 9 that the average difference in measurements, for a transducer located 1.5 ft in front of the pier, extends from 0.22 to 0.84 for mounting angles of 0 to 25 degrees, respectively. The data indicate that the minimum difference in sonar and point gauge measurements occur at mounting angles of 0 and 5 degrees. As the mounting angle increases, the measurement difference increases. Apparently, the transducer is detecting and measuring slope distances not necessarily related to the deepest portion of the scour hole.

The results of the mounting angle analysis indicated that transducer mounting angles of 0 and 5 degrees provide the highest level of resolution and accuracy of the sonar device. It is recommended that an angle slightly greater than 0 degrees

be used to ensure that the face of the transducer does not entrap air. Although mounting angles greater than 5 degrees may be used, slope distance adjustments to the measurements must be made.

A limited comparison was conducted between the 8- and 20-degree sonar instruments. Both devices were tested at 0-, 5-, and 10-degree transducer mounting angles with the transducer located immediately in front of the pier. The accuracy of the devices was similar. Insufficient data were collected to provide a meaningful conclusion.

### Temperature Effects on Sonar

The effects of water temperature on the 8-degree sonar transducer device were evaluated. The sonar device was mounted in the VA tube. The water temperatures used to test the sonar device ranged from 42°F to 96°F, as summarized in Table 4. Each sonar device measurement was recorded and compared with the point gauge measured depth for four transducer submergences at each temperature. The difference between each sonar and point gauge measurements as well as the average difference for each water temperature tested are presented in Table 4. It is observed that the accuracy of the device decreased as the temperature of the water decreased. In fact, the depth difference increased by an order of magnitude (0.05 to 0.525 ft) over the 54°F drop in water temperature. Figure 10 presents an indication of the difference in sonar and point gauge measurements as a function of the change in water temperature.

The test results indicate that the sonar device selected for field implementation must be equipped to compensate for temperature stratification in the channel as well as seasonal temperature variations. Therefore, a high-quality instrument is recommended that can adequately compensate for temperature variations.

### SUMMARY AND FINDINGS

In an attempt to evaluate the effectiveness and practicability of several scour hole monitoring concepts and instruments, a laboratory testing program was conducted using several model and near-prototype devices. A series of flume tests was conducted in which driven and falling rod model devices were tested and evaluated. Also, sonar measurement devices were tested in a sump and VA tube to determine the potential effects of water temperature and a transducer's transmission angle, mounting angle, submergence depth, and mounting distance from the pier on the accuracy and reliability of the device.

The results of the Phase I flume tests indicate that the vertically supported falling rod has merit for further laboratory and field testing. The blunt-ended rod tended to drive itself into the alluvium because of the vibration from the current. However, when a base plate three times the rod diameter was placed upon the end of the rod, the device appeared to function well in the alluvial bed material.

A scuba mouse was installed on a vertically supported driven rod. The results indicated that if sufficient clearance is pro-

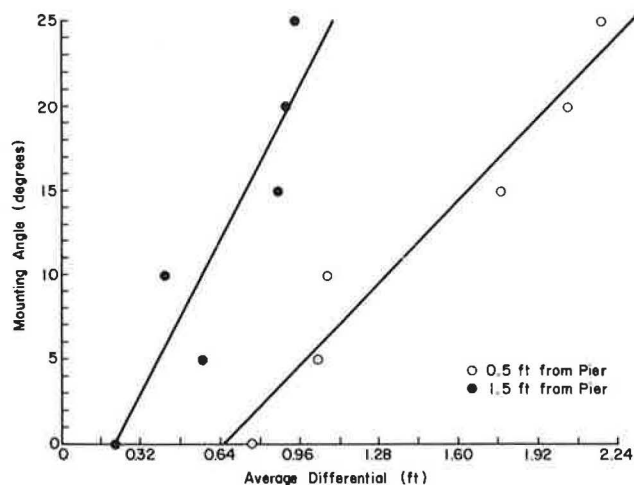


FIGURE 9 Representative comparison of measurement differences versus mounting angle.



TABLE 4 TEMPERATURE DATA SUMMARY OF SONAR TESTING

Test	Temp. (deg F)	Actual Depth (ft)	Finder Depth (ft)	Change in Depth (ft)	Avg. change in depth (ft)
1	96.0	6.25	6.30	0.05	0.050
		5.75	5.70	0.05	
		5.25	5.20	0.05	
		4.75	4.80	0.05	
2	86.0	6.25	6.30	0.05	0.075
		5.75	5.80	0.05	
		5.25	5.30	0.05	
		4.75	4.90	0.15	
3	78.0	6.25	6.40	0.15	0.225
		5.75	6.10	0.35	
		5.25	5.40	0.15	
		4.75	5.00	0.25	
4	65.0	6.25	6.60	0.35	0.425
		5.75	6.20	0.45	
		5.25	5.70	0.45	
		4.75	5.20	0.45	
5	54.0	6.25	6.60	0.35	0.325
		5.75	6.20	0.45	
		5.25	5.50	0.25	
		4.75	5.00	0.25	
6	42.0	6.25	6.80	0.55	0.525
		5.75	6.20	0.45	
		5.25	5.80	0.55	
		4.75	5.30	0.55	

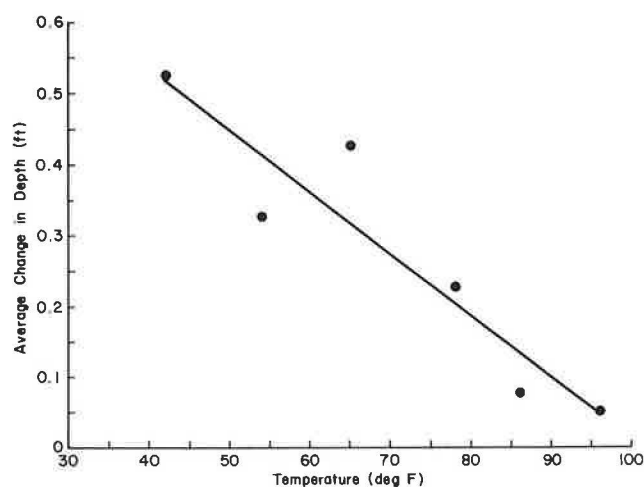


FIGURE 10 Average difference in sonar and point gauge measurements versus water temperature.

vided between the ring and the rod, the device has merit for further laboratory and field testing.

Two concepts were tested with limited success. The vertically supported falling rod was placed immediately upstream of the pier through the footing. The presence of the device did not influence the dimensions of scour. However, the rod did not fall freely because of the bed material binding the device. An angle-supported falling rod was also installed and tested. Because of the rod angle, the device monitored a location upstream of the deepest portion of the scour hole. The measured depth did not correlate well to the maximum depth of scour.

Sonar devices were tested in a laboratory sump and VA tube to determine the applicability of the sonar device for reliable field use. The results indicate that the sonar device should be laboratory- and field-tested further. It was observed that the instrument is sensitive to water temperature, to transducer mounting angle, and to transducer placement location in front of the pier. The instrument is insensitive to the depth of transducer submergence.