# Scour-hole Dimensions at Selected Bridge Piers in New York

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**Abstract** Knowledge of scour-hole dimensions can be used by bridge engineers to determine the extent of countermeasures needed to prevent scour at bridge piers. Scour-hole widths at 128 piers, and scour-hole lengths at 40 piers were computed. These dimensions are a function of scour depth and the average slope of the streambed in a scour hole. Average streambed slopes in a scour hole were generally less than 15°, and most maximum slopes were less than 27°. The median scour-hole width measured perpendicularly from the upstream side of a pier was 2.7 m, and large widths were common at sites with debris. The median ratio of scour-hole width to scour depth was 4.7, and the median ratio of scour-hole width to pier width was 1.6. The maximum ratio of scour depth to pier width was 1.7. The median scour-hole length measured upstream from a pier was 3.6 m, and the median length measured downstream from the nose of a pier was 5.6 m. The median ratio of upstream scour-hole length to pier width was 2.5 and the median ratio of downstream scour-hole length to pier length was 0.4. The lowest streambed elevation in a scour hole was commonly less than 1 pier width from the upstream side of a pier.

**Introduction** Knowledge of scour-hole dimensions can be used by bridge engineers to determine the extent of countermeasures needed to prevent scour at bridge piers and to evaluate whether adjacent scour holes can overlap one another and decrease streambed elevations at piers or abutments. The topwidth of a scour hole has been found to be a function of scour depth ($Y_s$) and the angle of repose of the bed material; thus, topwidth can be calculated from the angle of repose of bed material in air (30-44°) (Richardson and others, 1993; Richardson and Abed, 1993). (Angle of repose is the maximum slope angle upon which noncohesive material will rest without moving and is a measure of the intergranular friction of the material).

Methods used in this study analyze each side of a pier separately, while Richardson and others (1993) calculated the topwidth of a scour hole by summing the scour-hole widths at the left, right, and upstream sides of a pier. The scour-hole widths described in this study can be related to the topwidths of symmetric scour holes by the following equation,

$$\text{Scour-hole width} = 1/2\ (\text{Topwidth} - \text{Pier width}) \qquad (1)$$

Richardson and others (1993) suggest a value of $2.8Y_s$ as a general estimate of topwidth. This study found scour-hole widths to be $4.7Y_s$ and streambed slopes in scour holes to be less than the angle of repose of bed material in air.

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**Scour-hole Measurement** Streambed elevations were computed from USGS scour and streamflow measurements and from New York State Department of Transportation (NYSDOT) bridge-inspection data (Butch, 1991, 1993). The width of each scour hole was calculated from scour-hole and streambed measurements made at the upstream side of a pier. Widths at both the left and right sides of each pier were computed unless one side adjoined the streambank. The length of each scour hole was calculated from measurements made along both sides of each pier, but only the side adjacent to the main flow, deepest scour, or longest length was analyzed. The horizontal distance between streambed-elevation measurements in a cross section was important because spacing greater than a few meters can lead to inaccurate scour-hole dimensions. Distances between measurement points ranged from 0.5 to 3.0 m, and streambed elevations were measured to the nearest 5 cm. A method of analysis was developed so that a program could process the cross-section data and compute the elevation of the streambed in the scour hole.

**Scour-hole width** Scour-hole width, $W_s$ is the distance measured perpendicularly from the upstream side of a pier to the far edge of the scour hole, and as previously mentioned, about one half the topwidth of a scour hole. The ambient slope of the streambed was computed from a point five pier widths from the pier. The dimensions of the scour hole are related by the equation,

$$W_s = Y_s * \cot\phi, \qquad (2)$$

Where $Y_s$ is the scour depth, and
$\phi$ is the average slope of the streambed from the lowest elevation in a hole to the edge of the hole.

The analysis began at the lowest streambed elevation at each pier, or at the lowest elevation at the left or right side of a pier, and ended where one of the following conditions was met (1) the streambed elevation no longer increased with distance from pier, (2) the difference between the streambed slope in the scour hole and the slope of the ambient bed was less than 3°, (3) the streambed slope decreased over three successive measurements, or (4) the measurement was five pier widths from the pier.

Condition 3 assumes that the shape of the streambed in a scour hole is basically linear or concave. Scour holes that have convex shapes could have more than 3 successive measurements with decreasing slopes, particularly where the measurements are closely spaced.

A scour-hole width analysis of a 1993 scour measurement at Route I-90 over Schoharie Creek is shown in figure 1, where the left edge of the scour hole is identified by condition 3, and the right edge by condition 1.

**Scour-hole length** Scour-hole length, $L_s$, is the distance from the upstream side of each pier to the upstream edge of the scour hole (upstream length) or to the downstream edge of the hole (downstream length). The total length of the scour hole is equal to the sum of the upstream and downstream lengths. Scour-hole dimensions were measured and computed in a manner similar to those described for width dimensions, except that the computed slope of the ambient bed was 5 to 10 m upstream from the pier and the cross section was parallel to the pier rather than perpendicular.

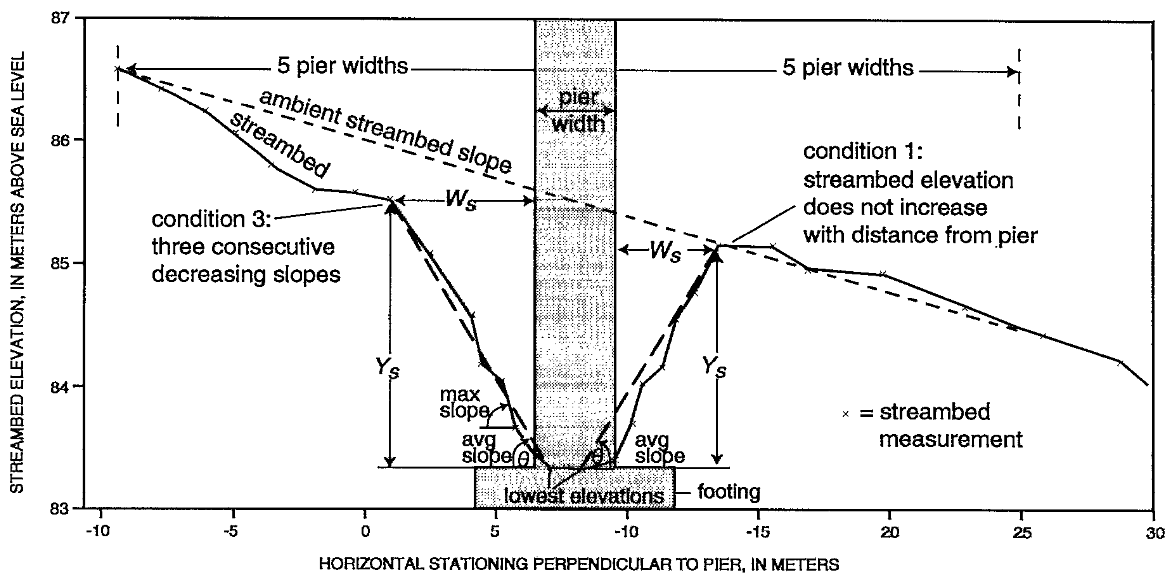


Figure 1. -- Scour-hole width analysis at Interstate 90 over Schoharie Creek.

The analysis began at the lowest streambed elevation at each pier and ended where one of the following conditions was met (1) the streambed elevation no longer increased, (2) the difference between the streambed slope in the scour hole and the slope of the ambient bed was less than 3°, or (3) the streambed slope decreased over three successive measurements. Condition 3 assumes the same scour-hole shape as the width analysis. A scour-hole length analysis of a 1987 NYSDOT scour measurement at State Route 62 over Conewango Creek is shown in figure 2, where the upstream edge of the scour hole is identified by condition 1, and the downstream edge by condition 3.

**Scour-hole Dimensions** Scour-hole widths at 128 piers, and lengths at 40 piers were computed. Multiple measurements were included at piers where scour holes were deepened or the elevation of the ambient bed was increased by more than one high flow. These dimensions may not represent the maximum scour at sites where the duration, frequency, or intensity of flows was insufficient (Butch, 1994). The extent of debris during historic floods is unknown.

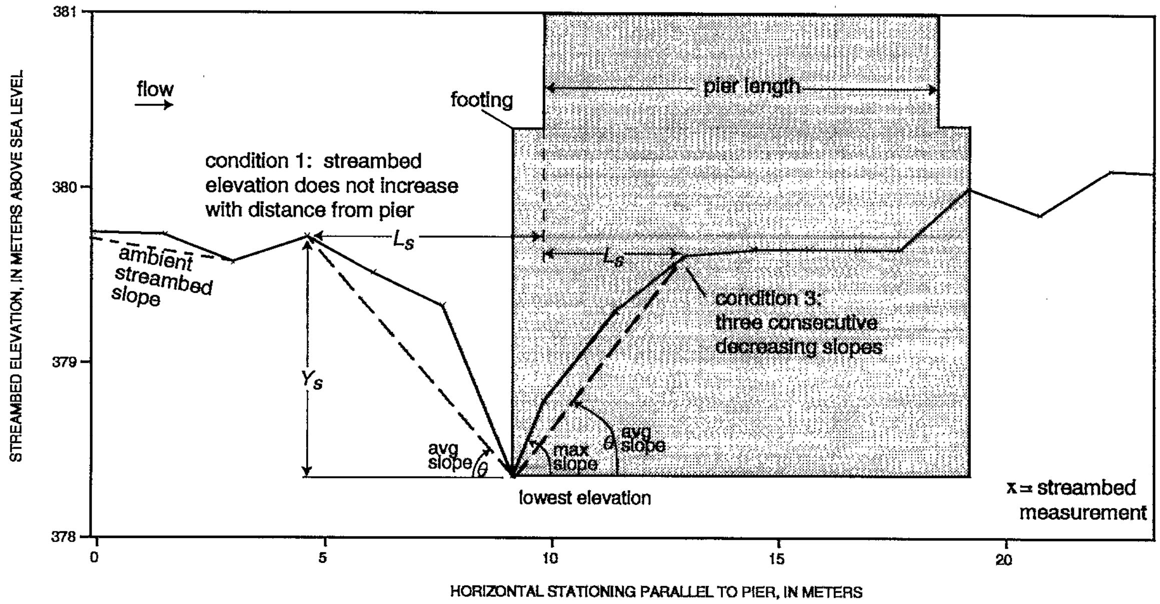


Figure 2. -- Scour-hole length analysis at State Route 62 over Conewango Creek.

**Scour-hole width** The median width at 128 piers was 2.7 m, and 75 percent of the widths were less than 4.9 m (fig. 3a). A minus sign in front of a width corresponds to scour holes that did not extend beyond the pier. The median pier width was 1.5 m, and 75 percent of pier widths were less than 2.1 m (fig. 3b). Large scour-hole widths were common at sites with debris; major debris piles increased the effective widths of three piers to 5 m, 9 m, and 14 m. The extent of debris at one bridge where scour-hole widths exceeded 10 m is unknown.

The median scour depth was 0.6 m, and 75 percent of the scour depths were less than 0.8 m (fig. 3c). A histogram of the ratio of scour-hole width to scour depth ($W_s/Y_s$) is shown in figure 3d; the median was 4.7, and 75 percent of the sites had ratios less than 7.4. The three ratios greater than 35 correspond to sites where scour depth was less than 0.5 m. The distribution of scour-hole width to pier-width ($W_s/P_w$) is shown in figure 3e; the median was 1.6, and 75 percent of the ratios were less than 2.8. Ratios greater than 7.0 correspond to sites where scour-hole widths exceeded 10 m, but the extent of debris is unknown. The distribution of scour-depth to pier-width ($Y_s/P_w$) is shown in figure 3f; the median was 0.3, 75 percent of the ratios were less than 0.5, and the maximum was 1.7.

The distribution of average streambed slopes within a scour hole is shown in figure 3g; the median was 8.8°, and 75 percent of the slopes were less than 12.7°. Average slopes less than the angle of repose in air indicate that these holes may deepen before widening or that the angle of repose in turbulent flow near a pier is less than the angle of repose in air. The maximum average slope, 34.6°, corresponds to the deepest scour hole, 2.3 m, and indicates that the hole may widen if the scour depth increases or the bed material is noncohesive. A

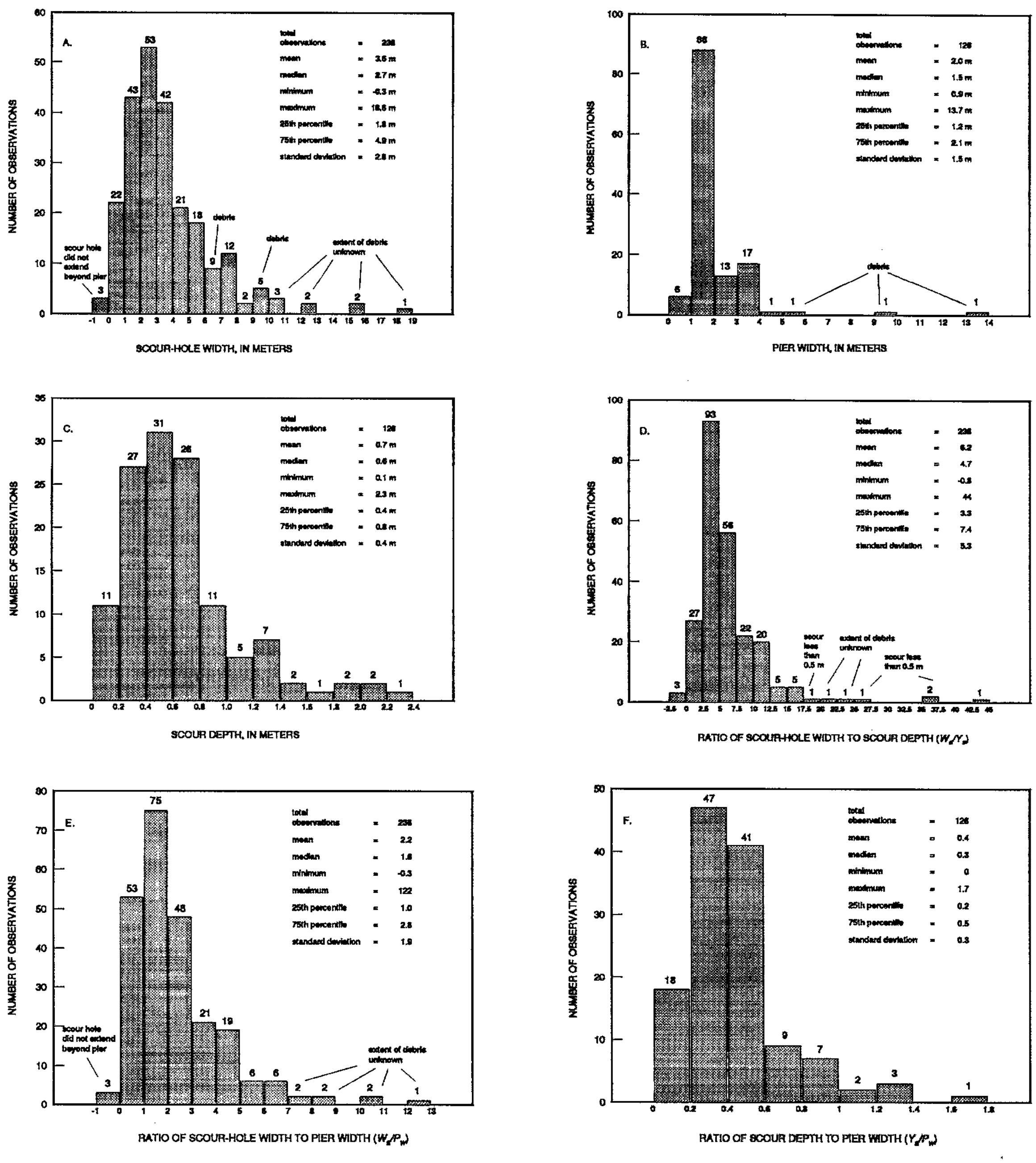


Figure 3. -- Distribution of factors that determine widths of scour holes in New York streams.

histogram of maximum streambed slope in a scour hole is shown in figure 3h; the median was 19.3°, and 75 percent of the maximum slopes were less than 26.6°. Maximum slopes less than the angle of repose in air may result from conditions similar to those that produced shallow average slopes. Maximum slopes that exceeded the angle of repose in air may be attributed to cohesive material, cobbles, or debris in the streambed.

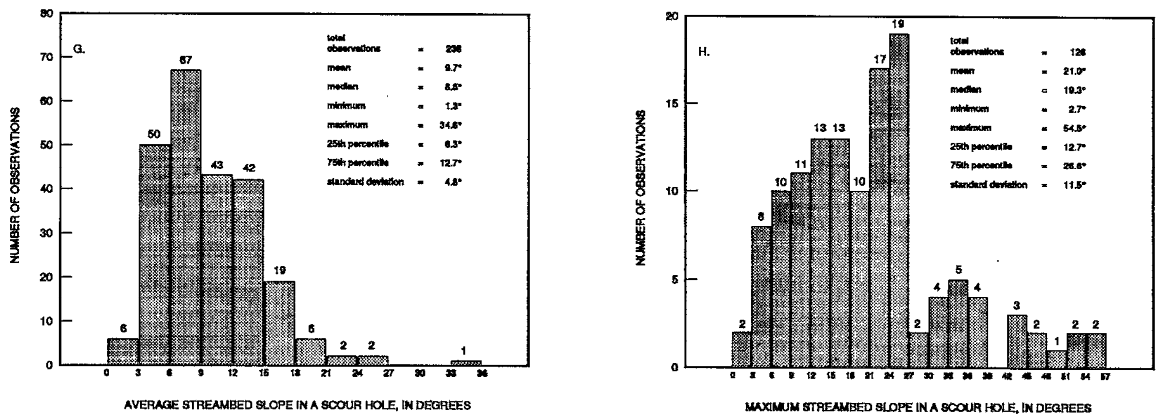


Figure 3. (continued) – Distribution of factors that determine widths of scour holes in New York streams.

**Scour-hole length** A histogram of upstream scour-hole length is shown in figure 4a; the median was 3.6 m, and 75 percent of the values were less than 5.3 m. The median pier width was 1.5 m, and the median scour depth was 0.7 m. The distribution of upstream length to scour depth ($L_s/Y_s$) is shown in figure 4b; the median was 5.2, and ratios greater than 8.0 correspond to scour depths less than 0.5 m. The distribution of upstream length to pier-width ($L_s/P_w$) is shown in figure 4c; the median was 2.5, and 75 percent of the ratios were less than 3.8.

Downstream scour-hole lengths are affected by flow pattern, pier misalignment to flow, and contraction scour (streambed erosion caused by increased flow velocity near a bridge), and are generally greater than upstream scour-hole lengths. A histogram of downstream length is shown in figure 4d; the median was 5.6 m,and 75 percent of the values were less than 8.5 m. The distribution of downstream length to pier width ($L_s/P_w$) is shown in figure 4e; the median was 3.3, and 75 percent of the ratios were less than 6.1. The median pier length was 14 m. The distribution of downstream length to pier length ($L_s/P_l$) is shown in figure 4f; the median was 0.4, and 75 percent of the ratios were less than 0.6.

A histogram of average streambed slope in a scour hole upstream from a pier is shown in figure 4g; the median was 9.8°, and 75 percent of the slopes were less than 12.2°. Slopes less than the angle of repose in air may result from conditions similar to those that produced shallow streambed slopes for width measurements. The median average streambed slope downstream from the point of lowest elevation in a scour hole was 7.1°. Downstream

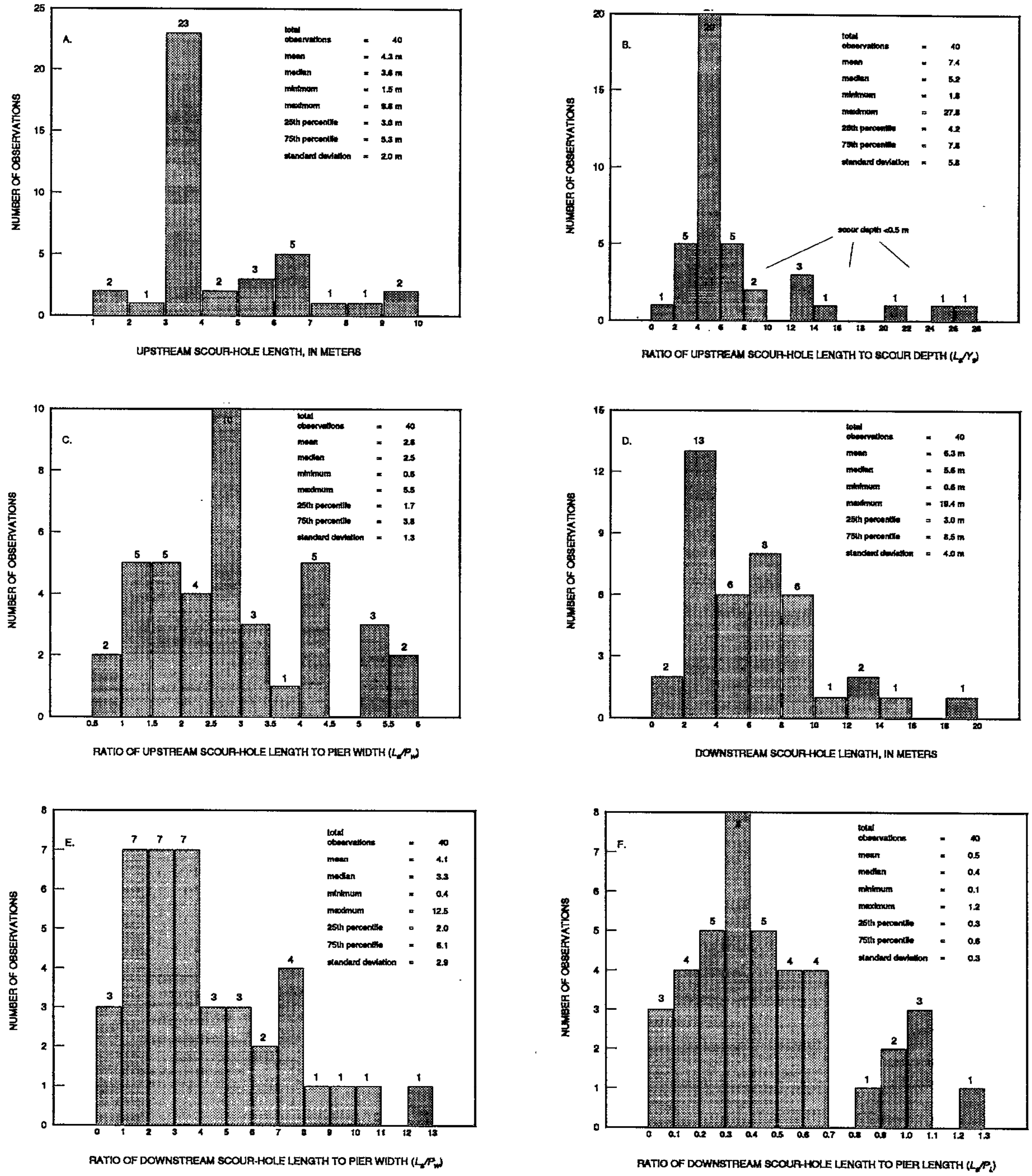


Figure 4. -- Distribution of factors that determine lengths of scour holes in New York streams.

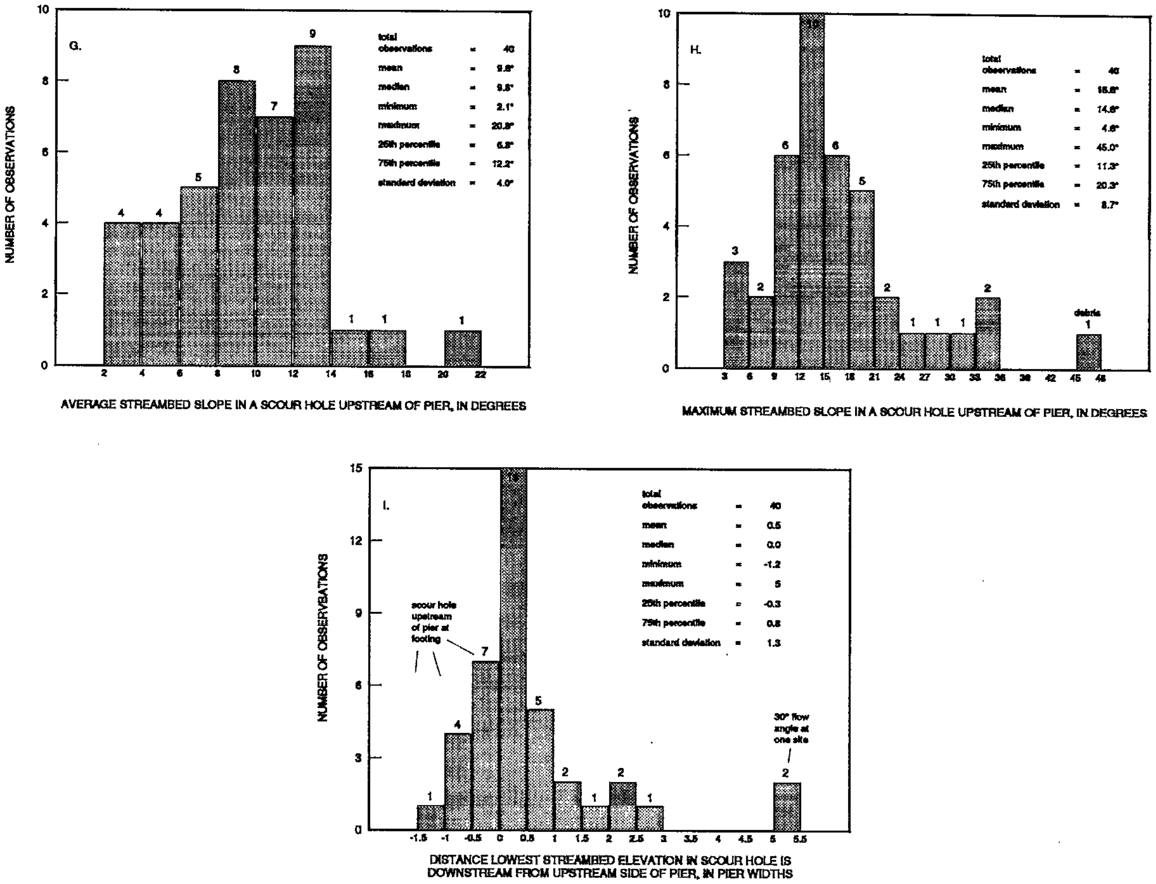


Figure 4. (continued) -- Distribution of factors that determine lengths of scour holes in New York streams.

slopes were less than upstream slopes because the flow pattern under a bridge generally caused downstream lengths to exceed upstream lengths.

A histogram of maximum streambed slopes in a scour hole upstream from a pier are shown in figure 4h; the median was 14.6°, and 75 percent of the maximum slopes were less than 20.3°. All slopes were less than the angle of repose in air except the steepest slope, which was affected by debris. The lowest streambed elevation of a scour hole was commonly at the upstream side or corner of a pier or spread footing and less than 1 pier width from the upstream side of a pier (fig.4i). At one site, a large (30°) angle between the flow and the pier caused the lowest streambed elevation to form five pier widths downstream from the upstream side of the pier.

**Summary** Scour-hole widths at 128 piers, and scour-hole lengths at 40 piers were computed. These dimensions are a function of scour depth and the average slope of the streambed in a scour hole, but may not represent the maximum scour at sites where the duration, frequency, or intensity of high flows was insufficient. The median width was 2.7 m, and large widths were common at sites where debris was found. Methods used in this study analyze each side of a pier separately, therefore, scour-hole widths are about one half the topwidth of a scour hole. Previous studies suggest a value of $2.8Y_s$ as a general estimate of topwidth. This study found scour-hole widths to be $4.7Y_s$ and streambed slopes in scour holes to be less than the angle of repose of bed material in air. The median ratio of scour-hole width to pier width was 1.6 and the maximum ratio of scour depth to pier width was 1.7.

The median upstream scour-hole length was 3.6 m, and the median downstream length was 5.6 m. The median ratio of upstream length and scour depth was 5.2, and the median ratio of upstream length and pier width was 2.5. Downstream lengths were affected by the flow pattern, pier misalignment to flow, and contraction scour. The median ratio of downstream length to pier length was 0.4.

The lowest streambed elevation in a scour hole was commonly less than 1 pier width from the upstream side of a pier, although a 30° angle between the flow and one pier caused the lowest streambed elevation in a scour hole to be 5 pier widths downstream from the upstream side of the pier. Average streambed slopes in a scour hole were generally less than 15°, and most maximum slopes were less than 27°. Slopes less than the angle of repose in air indicate that these holes may deepen before widening or that the angle of repose in turbulent flow near a pier is less than the angle of repose in air.

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