Flow Impingement Velocities, Snake River, Wyoming

Stephen T. Maynord,[1] A.M. ASCE

Abstract

Flow impingement, which occurs when approach channels direct flow into a bank line at large acute angles, results in flow concentration along bank lines, which creates large forces on bank material or bank protection. As part of studies conducted to determine the required riprap size for impinged flow, velocities were measured on the Snake River near Jackson, Wyoming. High velocities and steep water-surface slopes were observed at each impingement site.

Introduction

Many streams can be found in which the channel planform results in a high degree of hydraulic irregularity. A prime example is a braided planform in which multiple channels exist over a wide range of flow conditions. These multiple channels tend to migrate due to erosion and deposition processes typically found in alluvial channels. Migration rates can be quite rapid when upstream midchannel islands and bars are breached or when logjams give way. Channel migration often leads to flow being directed against bank lines at large acute angles, which is referred to herein as "flow impingement." Flow impingement results in significant stress on the bankline, and channel protection is often required to maintain channels in a fixed position. The maximum attack often occurs at intermediate rather than high discharges because high discharges tend to submerge the midchannel islands and bars and the flow impingement tends to decrease. While the locations of flow impingement show some degree of regularity, entire channel reaches must

---

[1]Research Hydraulic Engineer, Hydraulics Laboratory, US Army Engineer Waterways Experiment Station, 3909 Halls Ferry Road, Vicksburg, MS 39180-6199.

often be protected because the locations of flow impingement cannot be predicted with enough certainty to leave some areas unprotected. Not only are bank lines subjected to high velocity, but also deep scour is found at impingement sites and undermining of bank protection is a common occurrence.

An example where flow impingement is a problem is the Snake River near Jackson, Wyoming, which is a braided stream that has levees on one or both sides of the channel that are almost completely protected with riprap revetment. The levees in this reach average about 1,500 ft (1 ft = 0.31 m) apart, and the river appears in some areas to meander between the levees while in other areas the braided planform is evident. This upper reach of the Snake River has a slope of about 0.0036 ft/ft, and the peak runoff is snowmelt, which generally occurs in early June. The mean peak discharge is 12,000 ft^3/s (1 ft^3/s = 0.028 m^3/s), and 90 percent of the years have a peak discharge of 18,000 ft^3/s or less. In 1986, a major event occurred with a peak discharge of 25,600 ft^3/s. The largest known flood occurred in 1894 with an estimated peak of 41,000 ft^3/s. The bed material in this reach is sand and gravel ranging up to a maximum size of 0.5-0.8 ft. The size of the riprap on the levees varies widely as does the unit weight of the stone. The levee slope is 1V:2H, and the larger stone in the riprap gradation is placed near the toe of the slope.

The overall objective of this study is to develop guidance for design of riprap under flow impingement. The scope of the study reported herein was to observe and document the characteristics of flow impingement zones including near-bank velocities and depths, water-surface slopes, and alignments. Information obtained from this field study will be used to investigate riprap size in a physical model.

Description of Tests and Results

On 5 June 1991, the river was inspected and 14 areas of significant impingement were found in the project reach. Velocity measurements were made at 8 of these sites, as shown in Figure 1. Future efforts of this type should also obtain aerial photographs of the project just before measurements are conducted. The measurements reported herein were collected between 6-8 and 10-12 June 1991, which was the peak runoff period for 1991. The mean daily discharge at below Flat Creek (downstream of Wilson Bridge) was 14,000 ft^3/s on the 6th, 14,500 ft^3/s on the 7th and 8th, 15,000 ft^3/s on the 10th, 15,500 ft^3/s on the 11th, and 16,000 ft^3/s on the 12th, and began to fall on the 13th. Therefore, 1991 had an above-average runoff. The water-surface elevation during

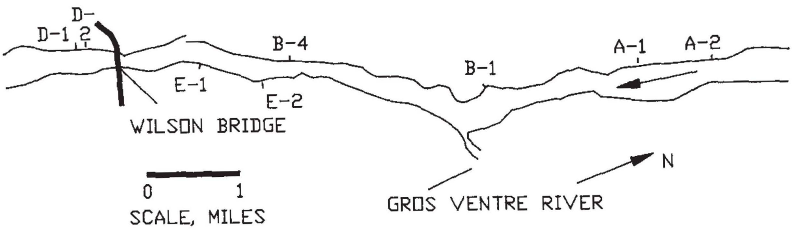

Figure 1. Snake River Project Reach and Impingement Sites

6-12 June was near the top of many of the midchannel bars.

Price and electromagnetic velocity meters were mounted on lead fish and supported by an extendable boom crane that could reach up to 40 ft from the bank line, as shown in Figure 2. Initially, a 100-lbm (1 lbm = 0.454 kg) lead fish was used, but this was swept too far

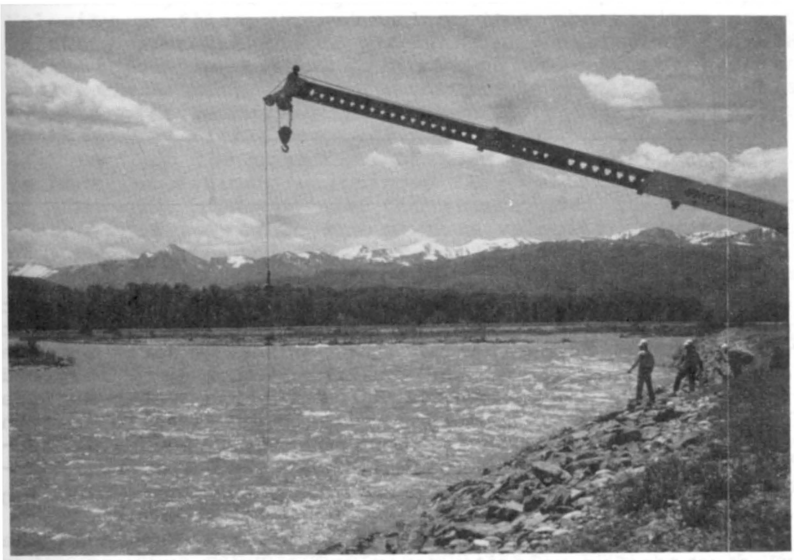

Figure 2. Crane at Velocity Site B-4

downstream; and a second lead fish weighing 140 lbm was attached below the first one. Future studies should use a single 200 to 250-lbm lead fish for the high velocities encountered in this study. A graduated tape was attached both horizontally and vertically to the cable supporting the meter to determine the position of the meter. Bottom position was noted when the fish hit bottom and the cable deflected. Future studies should consider some type of electronic depth meter. Debris was a problem, and the velocity meter had to be frequently raised to prevent damage. In most cases the typical impingement site had a wide, shallow approach channel that gradually converged toward the impingement site. The angle of the approach flow ranged from about 45 to 75 deg (1 deg = 0.017 rad). Midchannel bars were often present, as shown in Figure 3,

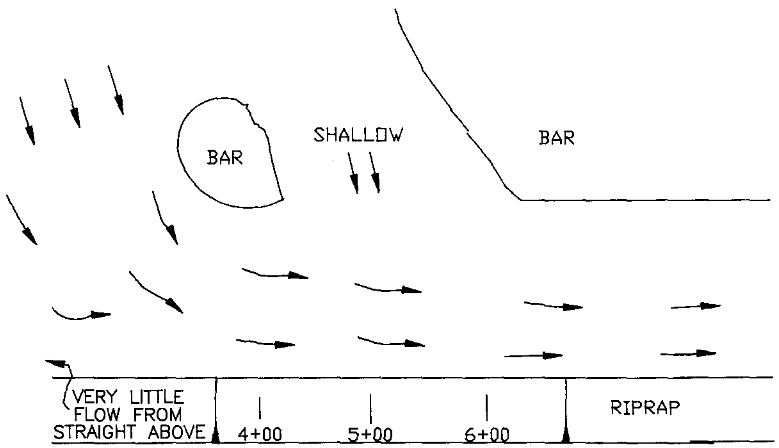

Figure 3. Plan of Site A-1 (not to scale)

which is site A-1. Velocities were taken at the apparent point of main attack (designated station 5+00) and 100 ft upstream and downstream of that point. Water-surface elevations relative to an arbitrary datum were measured from station 2+00 to 8+00 to establish water-surface slope. A plot of observed velocities at site A-1 on 7 June at station 4+00 is shown in Figure 4. Water-surface slope at station 4+00 was about 0.0066 ft/ft. Measurement of riprap size at site A-1 showed an average W_{50} of about 150 lbm.

A comparison of velocities at site A-2 between the electromagnetic velocity meter and a Price current meter resulted in surprisingly similar cross-section velocity plots. The maximum local water-surface slope at all impingement sites ranged from 0.0053-0.0159 ft/ft with an average of 0.0097 ft/ft or about 2.5-3.0 times the overall stream gradient. Most sites had maximum point velocities exceeding 14 ft/s (1 ft/s = 0.31 m/s). Maximum depth-averaged velocity exceeded 12 ft/s at most sites,

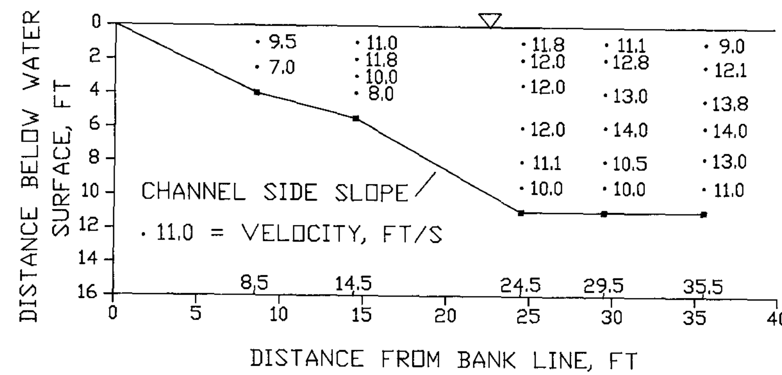

Figure 4. Velocities at Site A-1, 7 June, Station 4+00

and similar to sharp bendways, depth-averaged velocity remained high over a significant part of the side slope. Velocity profiles were skewed so that the maximum point velocity over the toe of slope often occurred at 0.4-0.6 depth above the bottom. This type of velocity profile would place much greater stress on a revetment than a typical profile having the maximum point velocity closer to the water surface.

Part of the objective of this study was to develop methods for estimating impinged flow velocities in braided channels. One of the techniques used in meandering channels is to relate the maximum velocity in a bend to the average channel velocity at the bend entrance. In sharply curved bends, the ratio of maximum side slope velocity to average channel velocity generally ranges up to 1.5. Impingement sites are simply poorly aligned bendways. Defining the average velocity in the channel approaching the impingement point is not as straightforward as it is in single channels. One option would be to use the average channel velocity from a HEC-2 water-surface profile computation for a discharge of 15,000 ft^3/s. Water-surface profiles were previously computed by the US Army Engineer District, Walla Walla, for a discharge of about 25,000 ft^3/s. At this discharge, the midchannel bars are submerged and flow is generally parallel to the levees. At a discharge of 15,000 ft^3/s, flow is confined to the single or multiple braided channels that are not parallel to the levees. To use HEC-2 for flow within the braided channels would require cross-section data far beyond what was used for the 25,000 ft^3/s discharge. As an alternative to HEC-2, the cross-sections used in HEC-2 were analyzed to determine the cross-sectional area below the top of the midchannel bars in locations where the river was confined to a single channel. This area was selected because the most severe impingement generally occurs when the river is confined to a single channel and when the discharge produces a stage near the top of the midchannel bars. Unfortunately only one cross-section meeting these requirements occurred near the velocity sites reported herein. At site B-4 the single channel area was 1,600 ft^2 and stages during June 1991 were close to the tops of the midchannel bars, indicating the measurements reported herein were close to the maximum in terms of velocity magnitude. Using a discharge of 15,000 ft^3/s and an area of 1,600 ft^2 resulted in an average channel velocity of 9.3 ft/s. The maximum depth-averaged velocity measured at site B-4 near the toe of the riprap revetment was 12.4 ft/s, giving a ratio of maximum depth-averaged velocity to average channel velocity of 1.33, which is reasonable based on results from meandering channels. More data are needed to test this approach.

Discussion of Results and Conclusions

Flow impingement on the Snake River results in depth-averaged velocity exceeding 12 ft/s near the revetted levees. Maximum point velocities were up to 16 ft/s. Typical impingement points had flow approaching the levee at 45-75 deg. A method for estimating impingement velocities is proposed herein, but additional verification is needed.

Acknowledgement

The tests described and the data presented herein were obtained from studies sponsored by the Office, Chief of Engineers as part of the Flood Control Research Program and conducted by the US Army Engineer Waterways Experiment Station, Vicksburg, MS. Permission was granted by the Chief of Engineers to publish this information. Messrs. Don Barney and Conan Beasly of Teton County are thanked for their support during the field tests.