

# Experimental study on Bendway weirs

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**ABSTRACT:** Bendway weirs have been applied as a counter measures for outer bank erosion. The hydraulic effects of the weirs reduce erosion on the outer bank of the bend by redistribute the flow patterns in river bend. Despite many studies conducted, the design criteria are not based on technical design procedure. Therefore it is the purpose of this study to investigate the effects of bendway weirs spacing on bed topography; this study was conducted on a 90 degree flume bend in the hydraulic laboratory of Shahid Chamran University. Series of structures were placed on three different spaces. Tests are conducted under different flow conditions. Bed topography was measured after each test. From the analysis of this study it was found that the location of scour hole moves from the outer bank, where there are no bendway weirs to the centre, for the case if bendway weirs are used. The maximum scour hole depth along the outer bank is generally reduced and shifted toward the centre at most of the tests. The results of this study can improve the design process of the bendway weirs for use in river bend

*Keywords: Bendway weir, submerged weir, bank erosion, river bend*

## 1 INTRODUCTION

In a typical river bend, surface water currents tend to move from the inner bend toward the outer bend, concentrating flow and increasing flow velocity along the outer bank of the bend. A secondary flow current also is developed in river bend. Another most important characteristic of flow in river bend is the general helical current induced by the balance of centrifugal force and the gravity force. Such higher velocities, secondary flow and general helical current can lead to outer bank erosion and formation of point bar in the inner bank. In addition when the flow is affected by pattern of the secondary current, the piloting of a vessel is very difficult. This is because surface flow pushes the vessel toward the outer bank.

Over the past years several measures have been investigated to improve the flow pattern in river bend for the purpose of reducing outer bank erosion or safe piloting. Submerged vane or Iowa vanes which have been extensively studied by Odgaard (2009) is an example of these techniques.

In recent years, submerged weir or bendway weir has become a popular method to control or reduce bank erosion along meandering rivers

(Abad et al. 2008). Rhoads (2003) stated that at in Illinois alone, bendway weirs have been installed at hundred sites. The technique originally was developed by the US Corps of Engineers to improve the navigation on the Mississippi rivers (Derrick, 1994). Over the past 20 years, the use of bendway weirs has shifted from navigation maintenance on large rivers to erosional control on small non-navigable rivers. Bendway weirs are low cost, stone made structures angled slightly upstream into the flow from outer bank of a river bend. When several weirs are installed around a bend, the effect is to deflect flow away from the outer bank throughout the entire bend. These structures also disrupt the helical motion of fluid that typically occurs in meander bends. By deflecting flow away from the outer bank and disrupting helical motion, the high shear stress near the base of the bank associated with the normal pattern of flow through a bend is altered, and the zone of high velocity and bed shear stress shifts toward the center of the channel.

Jia et al. (2005) studied the flow pattern of a river bend due to installation of bendway weirs both experimentally and numerically. They found that when the flow is affected by the bendway

weir, separation and recirculation will developed in the flow field. The general main flow alignment and the helical current will be influenced by the blockage of the river width. Figure 1 shows the flow pattern found by Jia et al.(2005) with the presence of bendway weirs in river bend.

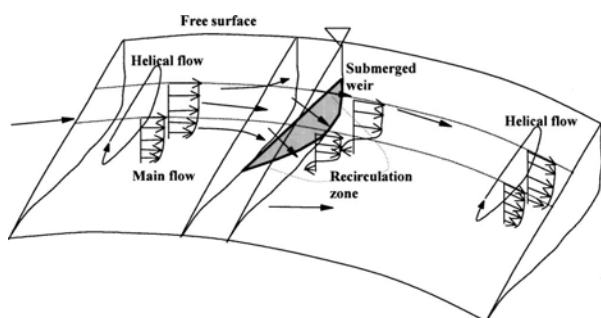


Figure 1 Flow structure around a bendway weir (Jia et al. 2005)

Jia et al (2009) a 3D numerical model of CCHE3D applied to simulate the flow patterns of Victoria bendway weirs. The purpose was to evaluate the hydraulic performance of bendway weirs in a natural river at various flow stages. They conducted field data at low stages and found that the bendway weirs produce three major hydraulic zones at low stage: 1) a region of stagnant or re-circulating flow between the weirs along the outer bank; 2) a thalweg inward of the weir tips characterized by a high-velocity core at the surface and decreasing velocities toward the bed and inner bank; and 3) a shear layer immediately downstream of the weir tips between the recirculating flow and the thalweg. Simulations of flow structure for medium- and high-flow conditions by CCHE3D models indicate that weirs tend to deflect the flow downward toward the bed in the lee of the weirs. These effects result in locally high boundary shear velocities on the bed in the lee of the weirs and along the outer bank above the tops of the weirs. Thus, although weirs generally protect the bank toe, they may lead to high shear stresses on the face of the outer bank. The results of three dimensional field flow velocity measurement and use of the three dimensional numerical model of CCHE3D conducted by Jia et (2009) clearly demonstrated that with the presence of bendway weir, the surface flow direction is aligned to the inner bank being favourable for navigation. The general helical secondary current pattern in the channel is redistributed by the presence of weir. In particular, bendway weirs modify the flow patterns at river bend as follow (Derrick, 1997): 1) deflect high-velocity near bed flow away from the outer bank. 2) increase flow resistance near the base of the outer bank, and 3) in-

hibit helical motion and re-distribution of momentum near the outer bank.

Current design criteria are based primarily on expert judgment rather than a technical design procedure. There are some criteria for design purpose as follow:

**Bendway weir height-** In the literatures no optimal height has been determined for bendway weir. The main criterion is that it should be between normal low flow and medium flow water surface (Derrick 1998, Smith and Wittler, 1998). Castro (1999) suggests maximum height should be between one-third and one-half average depth at the mean annual high water level.

**Angle of projection,  $\theta$ ,** between the bendway weir axis and the upstream bank line tangent typically ranges from 50 to 85 degrees. Experiments by Derrick (1994) resulted in a weir angle of 60 degrees being the most effective for the desired results in a physical model of a reach on the Mississippi River. Placement of weirs at higher angles will divide the flow instead of redirecting it and cause bank scalloping and erosion; lower weir angles will not redirect flow away from the bank (Derrick, 1997, 1998).

**Bendway weir length (L)** is primarily depends on the desired amount of thalweg replacement and shifting of the point bar (Derrick, 1997, 1998). Most designers describe length as related to the width of base flow, ranging from one-quarter (Derrick, 1997, 1998) to one-half (Derrick, 1997, 1998) of base flow width. It should not exceed one-third the mean channel width (W). Weirs designed for bank protection need not exceed  $\frac{1}{4}$  the channel width. A length of 1.5 to 2 times the distance from the bank to the thalweg has proven satisfactory on some bank stabilization projects.

**Spacing-Bendway weirs** should be spaced (S) similarly to spurs. Spacing can be taken as three to five times of weir length (Derrick, 1997, 1998).

Some investigators have pointed out that bendway weirs are effective bank erosion measures (Odgaard & Kennedy, 1983), but others indicate that bendway weirs in some cases have no or little effect on bank erosion. The purpose of this study is to conduct experimental tests to see the effect of bendway weirs on controlling bank erosion in a sharp river bend and to see the effect of spacing bendway weirs on shifting scour patterns toward inner bend.

## 2 MATERIAL AND METHODS

### 2.1 Experimental set-up

To reach the purpose of this study, a 90° bend flume was constructed in the hydraulic laboratory of Shahid Chamran University. The ratio of bend radius to the flume width is equal 2. The bend can be categorized as a sharp bend. Figure 1 show the experimental flume used in this study. Figure 2 shows a top view of the bend with weirs installed. A stilling tank was used at the beginning of the flume to supply a uniform water flow and several porous screens were used in order to prevent flow surface waves transfer to the flume. The height of flume 70 cm and the sediment thickness at the flume bed was 36 cm which is composed of natural uniform sand with average size of 1.26 mm.

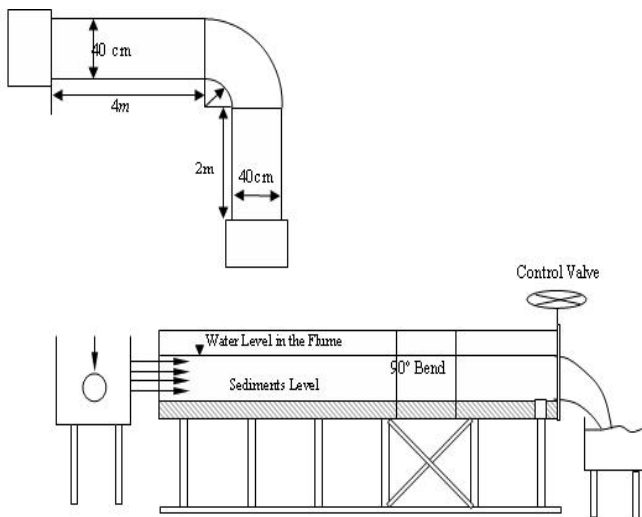


Figure 1. Schematic plan of the flume and 90° bend



Figure 2. View of 90° bend flume with weirs installed.

In order to prevent scouring in all experiments, the tail gate was kept closed at the beginning of each test and the water depth was increases gradually by opening of the inlet valve. After the desired discharge is reached, the tailgate was gradually opened until the desired uniform flow depth in the entire flume is reached. In this study Bendway weirs were made of wood. Length of each weir was equal 8 cm(less than one third of flume

width) and installed at angle of 60 degree upstream into the flow direction. The height of weir from the original bed was kept constant equal to one third of the flow depth equal to 5 cm. Three different spacing lengths of 24cm(3L), 32cm(4L) and 40cm(5L) were tested each under four different flow discharges of 10, 14, 18 and 22 lit/sec.

High flow conditions were applied in the tests program. Flow depth during all tests was kept constant as high as 15 cm so the weirs were submerged at all tests. Froude numbers in this study were equal to 0.14, 0.19, 0.25 and 0.30.

### 2.2 Tests with no bendway

The initial experimental tests were conducted in order to determine the incipient motion of particles in the flume with 90° bend. After a few tests the flow discharge of 25.16 lit/s with flow depth of 15cm was found to be the lowest discharge for our test program. In this situation the ratio of flow velocity to the velocity at incipient motion of sediment particles is equal to 0.95. For this test, the location of maximum scour depth in the outer bend occurs at downstream end of flume at location of 80° to 90°. Further experimental tests were carried out for discharges of 22, 26, 30 and 34 lit/s, respectively, and constant depth of 15cm. it should be noted here that in order to prevent the upstream sediment materials to move, the surface sediments were consolidated by using spray glue and therefore no sediments transfer was observed during the experiments. This means that although the flow discharge was higher than the incipient motion, the clear water condition was prevalent in all tests. To determine the relative equilibrium time for scour hole, a 12 hour long experiment with a discharge of 22 lit/s was conducted. During this test, maximum scour depth at the outer bend was measured at various time by a Point Gauge. Figure 3 shows the relative equilibrium time of 12 hours at 80° and 90° of outer portion of bend where maximum scour occurs. Scour depths are in mm whilst time is measured in minute. As it can be seen from Figure 3, maximum scour depth of 10.4cm is happened after 12 hours, whilst scour depth of 9.2cm can be reached at 90 min. This indicates that 85% of scour depth occurred during the first 90 min of the test. Thus all other remaining experimental tests, with or without bendway, lasted for 90 minutes.

### 2.2 Tests using bendway

For the purpose of this study, tests were conducted using series of bendway installed at the outer wall of the bend as can be seen in Figures 4 through 6. These photos are shown the scour pat-

terns around bendway for flow discharge of 22 lit/sec or Froude number=0.3. Bendway spacing in these photos is 5L, 4L and 3L respectively.

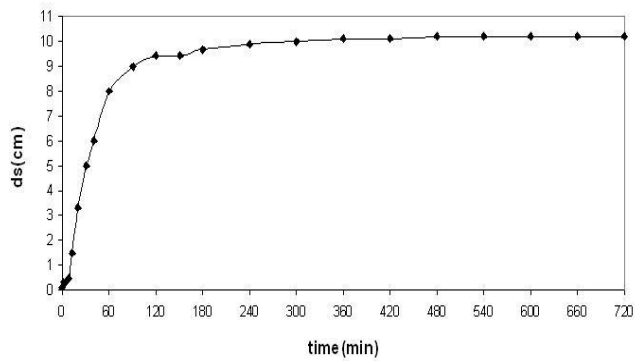


Figure 3. Scour depth (in centimetres) versus time (in minutes).



Figure 4 Bendway weirs at 5L spacing and Froude number equal to 0.3(looking downstream)



Figure 5 Bendway weirs at 4L spacing and Froude number equal to 0.3(looking downstream)

At the end of each test, bed topography was recorded using bed profiler instrument. These data then were used to plot the bed topography of the bend. Figure 7 and 8 show the results for the case of without and with bendway weirs at 3L spacing. The Froude number in both figures was 0.3.



Figure 6 Bendway weirs at 3L spacing and Froude number equal to 0.3(looking downstream)

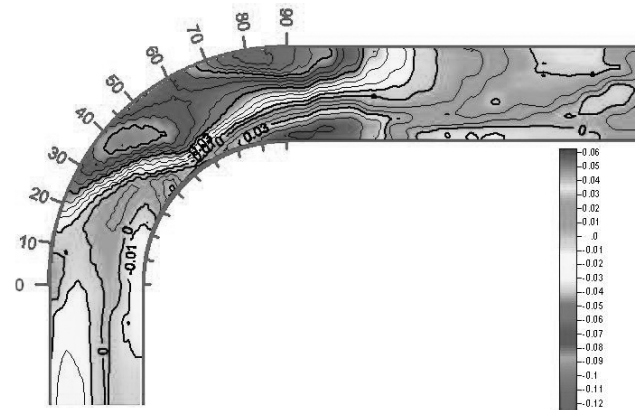


Figure 7 Bed topography with Bendway weirs at 3L spacing and Froude number equal to 0.3

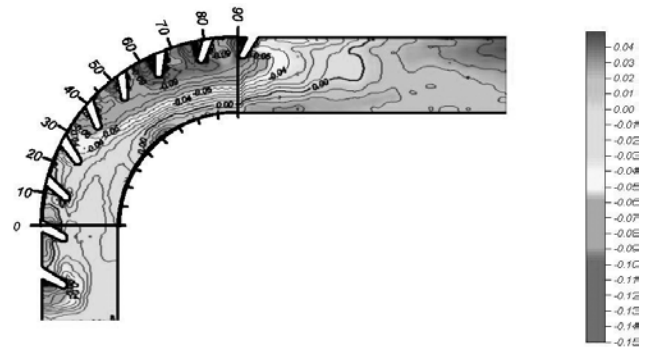


Figure 8 Bed topography without Bendway and Froude number equal to 0.3

### 2.3 Measuring devices

Bed topography of the flume at the end of each test was measured using a bed profiler instrument. Flow discharge measured by the V-notch weir at the downstream end of the flume. The flow depth measured by point gage.



### 3 RESULTS

During the experimental test, it was observed that in almost all tests, the first stages where sediment particles began to move was near the outer bend. During early experiments, the sediment movement began from 15° to 20° and transported to the inner portion of the bend. It was obvious that as the secondary flow expanded over this region the sediment particles moved earlier to the inner bend. It should be noted also that in experiments without bendway the unevenness of the flume bed was less in inner bend whilst it was more obvious in outer bend; however, by using a series of bendway this situation was corrected. On the other hand, maximum erosion, on average, occurred in experiments without bendway around 85° to 90° of outer bend whilst when bendway was used it would occur in less than 45° to 60° of edge of weirs. This means that the scour hole shifts from downstream end to the upstream and from outer bank to the center. Other experiments were conducted to study bendway spacing length effects. The results of the bendway effects in all experiments are presented in Figures 9 through 11 for 3L, 4L and 5L spacing respectively. These figures show the scour depth at the edge of each bendway for different flow discharge. In each figure, the scour depth increases as flow discharge increases. By comparison of these figures, it can be seen that for bendway spacing of 4L less scour depth occur.

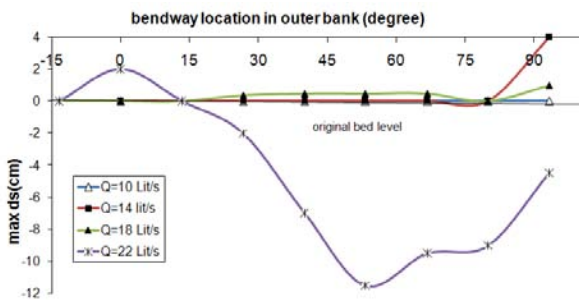


Figure 9 maximum scour depth in outer bank at various discharge versus bendway location (weir spacing, S=3L)

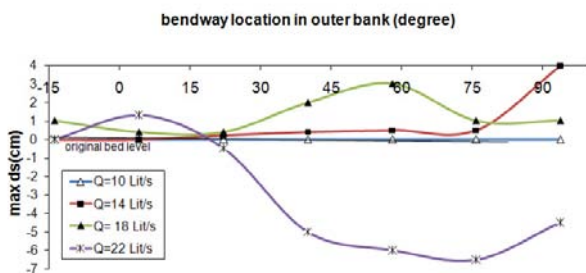


Figure 10 maximum scour depth in outer bank at various discharge versus bendway location (weir spacing, S=4L)

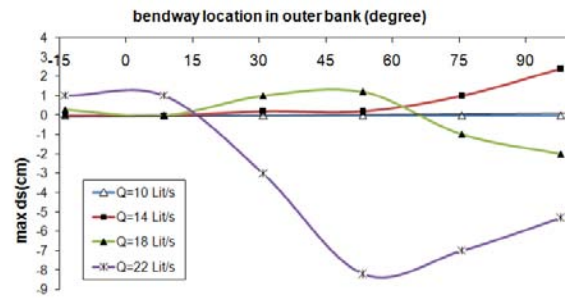


Figure 11 maximum scour depth in outer bank at various discharge versus bendway location (weir spacing, S=5L)

### 4 CONCLUSION

In this study experimental tests conducted in 90 degree flume bend to investigate the effect of bendway weirs spacing lengths on bed topography. Tests conducted with and without bendway. It was found that a scour holes develop around the bend. The main difference in bed topography with bendway weir is that the thawleg is not found to be located closed to the outer bank and it is shifted to the center of flume. The point of maximum scour hole also is shifted from the downstream end of flume further upstream. From the experimental results it was found that bendway weirs can reduce the bend scour and redistributes the scour patterns around the bed more uninformative. It was found that less scour depth at Bendway weirs spacing of 4L occurs.

### ACKNOWLEDGEMENT

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