CONTROL OF LOCAL SCOUR DEPTH AROUND BRIDGE PIER USING DOWNSTREAM BED SILL

Prof. Dr. Saleh I. Khassaf
Kufa University, Iraq
Email: alkhssafmustafa@yahoo.com

Associated Prof. Dr. Scott A. Yost
Kentucky University, USA
Email: yostsa@engr.uky.edu

Ali Adel Abulwahed
Kufa University, Iraq
Email: aliadelalzuhairi@yahoo.co.uk

Received: 27/9/2012; Accepted: 17/5/2013

Abstract

This study is based on laboratory experiments for computing depth of local scour around bridge pier when a downstream bed sill is used as a countermeasure. A circular section pier model has been used with clear water flow condition. However, sand was used as a bed sill.

Three different sizes of pier diameter are investigated with four different water depths and four different flow velocities. It is found that the diameter of the pier is an important parameter influencing the scouring process around the pier. Bed sills at different distances from pier downstream and with different width and thickness, were used as a countermeasure to reduce the local scour depth. The level of sill crest was the same elevation of bed material. As a result of the study, the analysis of experimental data shows that the usage of sill as a countermeasure structure has a beneficial reduction of scour around pier around 25% for flow intensity 0.95.

Keywords: Pier, Bed sill, Local Scour, Bridge

السيطرة على عمق الانحراف حول دعامات الجسور باستخدام عتبة القاع في الامتداد

Prof. Dr. Saleh I. Khassaf
Kufa University, Iraq
Email: alkhssafmustafa@yahoo.com

أ. د. سكوت
جامعة كنتاكي الأمريكية
Email: yostsa@engr.uky.edu

علي عبد الواحد
جامعة الكوفة
Email: aliadelalzuhairi@yahoo.co.uk

المؤتمر

مختص في اختبار مواد البناء

الخلاصة

في هذا البحث تم اعتماد تجارب مختبرية لحساب عمق الانجراف المتوقع حول دعامات الجسور باستخدام عتبة متدرجة. تم استخدام نماذج دعامات دائرية الشكل تحت ظروف الجريان الخالي من حمل الرسوبيات، باستخدام تربة الرمل كمادة للقاع، (clear-water condition)
1. Introduction

A common reason of bridge failures is local scour around bridge foundations such as piers and abutments. Local scour erodes the soil around the piers and reduces the lateral capacity of the foundations (Rambabu et al., 2003).

Local scour is the engineering term for erosion of the soil surrounding an obstruction caused by flowing water. The key element in the scour process is the formation of vortices due to pressure differences that occur when the water velocity profile meets the obstruction.

There are many reports about failure of bridges around the world due to scouring (Johnson et al., 1998, Melville and Coleman, 1999). This shows the importance of research on scouring in bridge design.

Flow pattern and mechanism of scouring around a bridge pier is very complex and has been reported by various investigators (Chabert and Engeldinger, 1956, Hjorth, 1975, Melville, 1975 and Dargahi, 1990). Briefly, the approach flow velocity goes to zero at upstream face of a pier and this cause an increase in pressure. As the flow velocity decreases from surface to the bed the dynamic pressure on the pier face also decreases downwards. This pressure gradient drives the flow down the pier resembling a vertical jet (Figure1). When this down flow impinges the streambed, it digs a hole in front of the pier and rolls up and by interaction with the coming flow forms a complex vortex system. This vortex extends downstream and passes the sides of the pier. Owing to its similarity to a horseshoe this vortex is called horseshoe vortex. The horseshoe vortex deepens the scour hole in front of the pier until the shear stress on the bed material becomes less than its critical shear stress.

The accelerating flow at two sides of the pier creates two slots in the streambed, which facilitates the transport of removed sediment from the scour hole.
at the upstream perimeter of the pier. The separation of the flow at the sides of the pier creates so called wake vortices. These vortices are unstable and shed alternatively. These vortices act as little tornadoes lifting the sediment from the bed and form their own scour hole.

Development of scouring with time depends on flow condition. If shear stress on bed is less than the threshold of sediment motion (clear water), scour develops first very rapidly and then approaches equilibrium asymptotically, whereas in live bed scour develops rapidly and its depth fluctuates in response to the passage of bed features, (Chabert and Engeldinger, 1956) (Figure 2). Maximum scour depth occurs at the threshold of sediment motion (Bureors and Raudkivi, 1991).

Grimaldi et al. (2009a) views the reduction of local scour as the main purpose of scour countermeasures. Lagasse et al.(2007) defines countermeasures as ‘measures incorporated into a highway-stream crossing system to monitor, control, inhibit, change, delay, or minimize stream instability and bridge scour problems.

The goal of the present work is to show the effectiveness of using a bed sill at specified location in the downstream as a counter measure against local scour which formed around pier.

![Flow Pattern around Pier](image)

**Fig.1 Flow Pattern around Pier.**
Fig. 2 Scouring in Clear Water and Live Bed.

1. Experimental Program

The laboratory flume used in this study is shown in Figure 3. The main flume structure is a glass fiber moulded in steel stiffeners which has a 6.6 m length, 0.4 m wide and 0.4 m depth.

The flume consists of an inlet tank 1m length in upstream, a working section 5.6 m is divided into three parts, in the middle layer of sand with depth and the length 0.1m and 2m respectively, it is filled with erodible uniform sediment. The upstream and downstream portion each have 1.25m length and the bed is raised 0.1m with compressed, coated and non swelling wood to obtain more stable water surface. The tank consists of three screens to avoid entering of any unwanted particles and debris into the working section of the flume.

The flume has closed system water. Water is supplied from the reservoir under the ground by a centrifugal pump that is situated on a fabricated steel base plate. The centrifugal pump lies beside the flume at upstream.

The depth of flow is controlled by an adjustable tail gate at the downstream of trap basin. For flow discharge measurement a sharp crested rectangular weir is
fabricated which have width of 0.4m and the height of 0.25 and it is mounted at the upstream section of flume.

All depth measurements are carried out using a point gauge with accuracy ±1mm mounted on a carriage which can move to any position above the working area transversely and longitudinally. The scour hole is obtained by performing 4-hours continuous run under clear water condition.

At the end of each experiments, the flume is carefully drained and sand bed level is straightened for next experiments with a scraper.

3. Pier Models

The pier model is fabricated from Polyvinyl Chloride (PVC) pipe. The bed sill used in the experiments was made of wood with a different thickness.

Three different sizes of circular piers of diameter 25 mm, 32 mm and 40 mm are used in the experimental program to simulate different practical situations
Different dimensions of bed sill are introduced and the spacing between the bed sill (Figure 4) and pier are changed to cover the aims of this work; see Table 1.

Table 1 Dimension of Sill.

<table>
<thead>
<tr>
<th>Thickness of sill</th>
<th>6 mm</th>
<th>12 mm</th>
<th>18 mm</th>
<th>24 mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width of sill</td>
<td>100 mm</td>
<td>200 mm</td>
<td>300 mm</td>
<td>400 mm</td>
</tr>
</tbody>
</table>

4. Sediment

The result of test showed that the bed material consists of cohesionless sand with a median particle size \(d_{50}\) equal to 0.714 mm. The geometric standard deviation of the sand size \(\sigma_g\) equal to 1.318.

According to classification of Alabi, 2006 \(\sigma_g = \sqrt{d_{84}/d_{16}}\), this size distribution is uniform. The sediments used in this study were well uniform, so that the results do not include the effect of sediment no uniformity in order to eliminate the reduction.
of local scour that would be expected to occur in non-uniform sand due to armoring effect.

As recommended by Melville 1997, the effect of sediment size can be ignored if the pier size to mean sediment size exceeds 25. This recommended have been conducted in present work.

![Fig.6 Grain Size Distribution Curve for Bed Material.](image)

5. The Experimental Work and its Purpose

The first four runs are made to determine the scour time at which the scour hole reaches to the equilibrium state with and without bed sill.

The runs from 5 to 25 test the flow velocity and depth of water with different pier diameter when the bed sill remains at same distance from the pier and the same dimensions. The runs from 26 to 34 test the spacing between the pier and bed sill.
for different diameter of piers when the flow velocity, water depth and bed sill dimension remain constant.

The runs from 35 to 43 test the thickness of bed sill for different diameter of piers when the flow velocity, water depth, width of bed sill and spacing between pier and bed sill remain constant.

The runs from 44 to 52 test the width of bed sill for different diameter of piers when the flow velocity, water depth, thickness of bed sill and spacing between pier and bed sill remain constant.

Fig. 7 Sketch Show the Parameter.
Table 2 Experimental Data.

<table>
<thead>
<tr>
<th>Run</th>
<th>Y (mm)</th>
<th>V (m/sec)</th>
<th>D (mm)</th>
<th>Vc (m/sec)</th>
<th>X (mm)</th>
<th>T (mm)</th>
<th>W (mm)</th>
<th>v/vc</th>
<th>Ds (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>20</td>
<td>0.23</td>
<td>25</td>
<td>0.2429</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>0.95</td>
<td>36</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>0.182</td>
<td>25</td>
<td>0.2429</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>0.75</td>
<td>18</td>
</tr>
<tr>
<td>3</td>
<td>20</td>
<td>0.23</td>
<td>25</td>
<td>0.2429</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.95</td>
<td>27</td>
</tr>
<tr>
<td>4</td>
<td>20</td>
<td>0.182</td>
<td>25</td>
<td>0.2429</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.75</td>
<td>11</td>
</tr>
<tr>
<td>5</td>
<td>25</td>
<td>0.241</td>
<td>25</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.95</td>
<td>28</td>
</tr>
<tr>
<td>6</td>
<td>25</td>
<td>0.228</td>
<td>25</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.9</td>
<td>22</td>
</tr>
<tr>
<td>7</td>
<td>25</td>
<td>0.215</td>
<td>25</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.85</td>
<td>19</td>
</tr>
<tr>
<td>8</td>
<td>25</td>
<td>0.19</td>
<td>25</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.748</td>
<td>10</td>
</tr>
<tr>
<td>9</td>
<td>35</td>
<td>0.19</td>
<td>25</td>
<td>0.27</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.703</td>
<td>11</td>
</tr>
<tr>
<td>10</td>
<td>45</td>
<td>0.19</td>
<td>25</td>
<td>0.282</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.6734</td>
<td>11.5</td>
</tr>
<tr>
<td>11</td>
<td>55</td>
<td>0.19</td>
<td>25</td>
<td>0.2917</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.6511</td>
<td>12</td>
</tr>
<tr>
<td>12</td>
<td>25</td>
<td>0.241</td>
<td>32</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.95</td>
<td>33</td>
</tr>
<tr>
<td>13</td>
<td>25</td>
<td>0.228</td>
<td>32</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.9</td>
<td>29</td>
</tr>
<tr>
<td>14</td>
<td>25</td>
<td>0.215</td>
<td>32</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.85</td>
<td>25</td>
</tr>
<tr>
<td>15</td>
<td>25</td>
<td>0.19</td>
<td>32</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.748</td>
<td>12.5</td>
</tr>
<tr>
<td>16</td>
<td>35</td>
<td>0.19</td>
<td>32</td>
<td>0.27</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.703</td>
<td>13</td>
</tr>
<tr>
<td>17</td>
<td>45</td>
<td>0.19</td>
<td>32</td>
<td>0.282</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.6734</td>
<td>13.5</td>
</tr>
<tr>
<td>18</td>
<td>55</td>
<td>0.19</td>
<td>32</td>
<td>0.2917</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.6511</td>
<td>14</td>
</tr>
<tr>
<td>19</td>
<td>25</td>
<td>0.241</td>
<td>40</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.95</td>
<td>37</td>
</tr>
<tr>
<td>20</td>
<td>25</td>
<td>0.228</td>
<td>40</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.9</td>
<td>33.5</td>
</tr>
<tr>
<td>21</td>
<td>25</td>
<td>0.215</td>
<td>40</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.85</td>
<td>28</td>
</tr>
<tr>
<td>22</td>
<td>25</td>
<td>0.19</td>
<td>40</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.748</td>
<td>15</td>
</tr>
<tr>
<td>23</td>
<td>35</td>
<td>0.19</td>
<td>40</td>
<td>0.27</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.703</td>
<td>15.5</td>
</tr>
<tr>
<td>24</td>
<td>45</td>
<td>0.19</td>
<td>40</td>
<td>0.282</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.6734</td>
<td>16</td>
</tr>
<tr>
<td>25</td>
<td>55</td>
<td>0.19</td>
<td>40</td>
<td>0.2917</td>
<td>0</td>
<td>12</td>
<td>400</td>
<td>0.6511</td>
<td>16.5</td>
</tr>
</tbody>
</table>

* Without bed sill
<p>| | | | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>26</td>
<td>25</td>
<td>0.241</td>
<td>25</td>
<td>0.2537</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>27</td>
<td>25</td>
<td>0.241</td>
<td>25</td>
<td>0.2537</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>28</td>
<td>25</td>
<td>0.241</td>
<td>25</td>
<td>0.2537</td>
<td>30</td>
<td>12</td>
</tr>
<tr>
<td>29</td>
<td>25</td>
<td>0.241</td>
<td>32</td>
<td>0.2537</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>30</td>
<td>25</td>
<td>0.241</td>
<td>32</td>
<td>0.2537</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>31</td>
<td>25</td>
<td>0.241</td>
<td>32</td>
<td>0.2537</td>
<td>30</td>
<td>12</td>
</tr>
<tr>
<td>32</td>
<td>25</td>
<td>0.241</td>
<td>40</td>
<td>0.2537</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td>33</td>
<td>25</td>
<td>0.241</td>
<td>40</td>
<td>0.2537</td>
<td>20</td>
<td>12</td>
</tr>
<tr>
<td>34</td>
<td>25</td>
<td>0.241</td>
<td>40</td>
<td>0.2537</td>
<td>30</td>
<td>12</td>
</tr>
<tr>
<td>35</td>
<td>25</td>
<td>0.241</td>
<td>25</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>36</td>
<td>25</td>
<td>0.241</td>
<td>25</td>
<td>0.2537</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>37</td>
<td>25</td>
<td>0.241</td>
<td>25</td>
<td>0.2537</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>38</td>
<td>25</td>
<td>0.241</td>
<td>32</td>
<td>0.2537</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>39</td>
<td>25</td>
<td>0.241</td>
<td>32</td>
<td>0.2537</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>40</td>
<td>25</td>
<td>0.241</td>
<td>32</td>
<td>0.2537</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>41</td>
<td>25</td>
<td>0.241</td>
<td>40</td>
<td>0.2537</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td>42</td>
<td>25</td>
<td>0.241</td>
<td>40</td>
<td>0.2537</td>
<td>0</td>
<td>18</td>
</tr>
<tr>
<td>43</td>
<td>25</td>
<td>0.241</td>
<td>40</td>
<td>0.2537</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>44</td>
<td>25</td>
<td>0.241</td>
<td>25</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>45</td>
<td>25</td>
<td>0.241</td>
<td>25</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>46</td>
<td>25</td>
<td>0.241</td>
<td>25</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>47</td>
<td>25</td>
<td>0.241</td>
<td>32</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>48</td>
<td>25</td>
<td>0.241</td>
<td>32</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>49</td>
<td>25</td>
<td>0.241</td>
<td>32</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>50</td>
<td>25</td>
<td>0.241</td>
<td>40</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>51</td>
<td>25</td>
<td>0.241</td>
<td>40</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
</tr>
<tr>
<td>52</td>
<td>25</td>
<td>0.241</td>
<td>40</td>
<td>0.2537</td>
<td>0</td>
<td>12</td>
</tr>
</tbody>
</table>

**6. Equilibrium Time**

In order to find a more realistic equilibrium scour time, four preliminary tests is made on single circular pier D = 25, for both cases without and with bed sill. Scour is recorded at different time intervals using a point gauge to measure the maximum scour at the nose of upstream pier.
As shown in the Figure 8, the scour depth has sharply increased during first 100 min of test duration and the development of scour become approximately constant. It is noticed that 95 % of the local scour can be achieved in 3.5 hours in both models that is refer that the sill located as a countermeasure does not have any appreciable influence on the equilibrium time of scour hole. For more accuracy a four hours were selected to be as equilibrium time.

**Fig.8 Development of Scour Depth with the Time for Pier with and without Bed Sill.**
7. Analysis and Discussion of Results

Estimating of maximum possible scour depth around bridge piers is an important step in the design of bridge pier foundation. To examine such a phenomenon, sets of experiments are performed using cylindrical models to represent the main shape used for bridge pier. Different pier size, flow depth and
flow intensity \( \frac{V}{V_c} \) have been conducted in the experimental program to show the geometric and flow parameters on scouring process. Table 2 illustrate these parameters.

The effectiveness of bed sill is about 25% reductions in the maximum scour depth in the front of the pier when the flow intensity equal to 0.95. It should be noted that the critical bed shear velocity for initiation of motion \( (v_c) \) were calculated by adopting the following equation as recommended by Melville and Coleman (2000), viz. 

\[
V_r = 0.0115 + 0.0125(d_{50})^{1.4} \quad 0.1\text{mm} < d_{50} < 1\text{mm} \quad \text{eq.(1)}
\]

\[
V_r = 0.0305(d_{50})^{0.5} + 0.0065(d_{50})^{-1} \quad 1\text{mm} < d_{50} < 100\text{mm} \quad \text{eq.(2)}
\]

The corresponding critical velocity, \( v_c \), which is dependent on the flow depth, can be determined from the logarithmic and from the velocity profile, that is 

\[
\frac{V_c}{V} = 5.75\log\left(5.53\frac{y}{d_{50}}\right) \quad \text{eq.(3)}
\]

**Spacing Between Pier and Bed Sill**

A set of experiments (12 runs) is conducted for evaluating the relationship between spacing between pier and bed sill and the scour depth. The resulting of the scour depth shown in Figure 9.

For \( X=0 \) the bed sill totally excludes the wake vortex system from the scour volume around the pier and alters the flow field, which is probably influencing on the horse shoe vortex. For \( X>0 \), the bed sill seems to act less on the horse shoe vortex, more on the lower part of the wake vortex system.

The scour depth increased 4.6% when the spacing between pier and bed sill increased from 0 to 30 mm. However the pier were further exposed at downstream sided as the sill distinct from its downstream. Figure 10 illustrate this visualization.
Fig. 9 Development of Scour Depth with Spacing between Pier and Bed Sill.

Fig. 10 Longitudinal Profile of the Bed for Pier Showing the Effect of Spacing between Pier and Bed Sill on the Scour Depth.
**Thickness of Bed Sill**

A set of experiments are conducting for evaluating the relationship between scour depth and thickness of bed sill. These experiments are shown in the Figure 11.

The scour decreases with increase the thickness of bed sill; this is probably because the surface area of impact with the wake vortex is increasing. This surface area is influence on the wake vortex and weakens. This weaken wake vortex will be influence on the horse shoe vortex due to interact between them which is decrease the sour depth.

The scour depth decreased by 5.2% when bed sill has thickness 24mm instead of 6mm.

**Fig. 11 Development of Scour Depth with Thickness of Bed Sill.**

**Width of Bed sill**

The width of bed sill does not influence on the scour depth all the times. The width of bed sill will be influence when the transverse distance of the scour hole greater than the width of the bed sill. As in previous parameter three pier sizes are used with different thickness of bed sill in order to feel its effect on the scour depth. The spacing between pier and bed sill, thickness of bed sill, depth flow and flow velocity are remains constant for all runs.
A set of experiments are conducting for evaluating the relationship between scour depth and width of bed sill. These experiments are shown in the Figure 12.

The value of the scour depth is probably increased by 7.5% when the transverse distance of the scour hole is greater than the width of bed sill because the transverse distance that conflict with wake vortex is decreased.

![Graph showing the relationship between scour depth and width of bed sill.](image)

**Fig.12 Development of Scour Depth with Width of Bed Sill.**

**8. Conclusions**

The problem of local scour around the circular pier and it protection with downstream bed sill has been studied experimentally. Under the limitations imposed on this investigation the following conclusions can be drawn.

a) The effectiveness of bed sill is about 25% reductions in the maximum scour depth in the front of the pier when the flow intensity equal to 0.95.
b) The increasing diameter of pier with bed sill is given increasing scour depth.

c) The scour depth increased for pier with bed sill by increasing the spacing between bed sill and pier, the scour depth increase by 4.6% when increased the spacing between pier and bed sill from 0 to 30 mm. Accordingly the experimental work and within the boundary conditions and limitation of a present study the well influences location of sill as a countermeasure were at x=0.

d) The scour depth decreased around 5.2% for pier with bed sill by increasing thickness of bed sill from 6mm to 24mm.

e) The beneficial reduction of scour depth to about 7.5% have been recorded with bed sill having the width more than the transverse distance of the scour hole that resulted without using a sill as a countermeasure.

f) As a conclusion, the sill located at x= 0 ,with a thickness T= 24mm and a transverse width =400 mm, having a more contribution towards a reduction of scour depth up to 25%. This conclusion however was a result of a boundary condition and limitation of a present work.

List of Symbols

ds  Depth of scour around the pier
D  Diameter of pier
$d_{50}$  Median size of the sediment particle
Fr$_p$  Pier Froude number ($Fr = V / \sqrt{gD}$)
g  Acceleration due to gravity
$\rho$  Water density
Re  Reynolds number
V  Mean approach flow velocity
$V_c$  Critical velocity
$y$  Flow depth
$\mu$  Dynamic viscosity
Spacing between pier and bed sill (face to face)
Width of bed sill
Thickness of bed sill

References


Science B.V., Amsterdam, The Netherlands, pp 893-920.