# BRIDGE SCOUR: THE VIEW FROM INSIDE THE PIER

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A set of videos describing scour around bridge piers is introduced. The footage was taken from the inside of several piers looking upstream. The piers were constructed of clear plastic. The flows were mobile-bed (live bed) flows, the highest of which were designed to model conditions at significant floods in medium to large sand-bed streams. The videos document not only scour around unprotected bridge piers, but also the performance of such scour countermeasures as riprap, cable-tied blocks, grout-filled bags and pier-attached vanes. At the highest flows tested, the videos capture the failure of some of these countermeasures.

***Key Words :*** *scour, bridge piers, floods, riprap, cable-tied blocks, grout-filled bags, pier-attached vanes*

## 1. INTRODUCTION

The purpose of this short paper is to introduce a DVD containing videos of scour around bridge piers. The DVD's are to be made available to participants at the 4th International Conference on Scour and Erosion, Tokyo, Japan, November 5 – 7, 2008. The DVD will also remain available from the author, who may be contacted at the e-mail address below the title of the paper.

The videos represent a unique record of local scour around bridge piers for the following three reasons.

- The videos were recorded looking upstream from the inside of four model bridge piers constructed from transparent plastic. They thus capture the intimate details of the process of scour around bridge piers. Two of the piers were rectangular in shape, and the other two were circular.
- The flow conditions used to model scour were scaled to be in the range of bankfull discharge in medium to large sand-bed rivers. Bankfull discharge represents a flood flow that often corresponds to a 2 to 5-year flood in alluvial rivers. So the videos provide a reasonable representation of how the bed of a sand-bed river responds to a significant flood.
- Not only is unprotected scour recorded in the videos, but also the response to the installation of riprap, cable-tied blocks, grout-filled bags, pier-attached vanes and submerged sheet piles. In several cases, the videos document the failure of these scour countermeasures.

Also included on the DVD is a scanned copy of the report that outlines the results of an extensive set of experiments on bridge scour, i.e. Parker et al. (1998). The videos were taken as part of this research program.

## 2. DESIGN AND SETUP

The research on bridge scour was conducted at St. Anthony Falls Laboratory, University of Minnesota, USA (abbreviated to SAFL below). Two flumes were used for this purpose: the Main Channel and the Tilting Flume. The Main Channel has a width of 2.7 m, a length of 77 m, a depth of 1.8 m. It was operated in sediment-recirculating mode. The Tilting Flume has a width of 0.9 m, a length of 15 m and a depth of 0.6 m. It was operated in sediment-feed mode.

The sand used in both flumes had a median size near 0.8 mm, and sizes ranging from 0.2 to 4 mm. The riprap used in the Main Channel had a median size of 54 mm; in the Tilting Flume the size was 22 mm. In both cases the riprap had a range of sizes to allow for interlocking. The material specific gravity of both the sediment and the riprap was near 2.65.

Four bridge piers constructed from transparent plastic were used. Two of these were circular, with a diameter of 0.305 m in the Main Channel and 0.102 m in the Tilting Flume. The other two were rectangular. In the Main Channel, the streamwise dimension was 0.905 m and the transverse dimension was 0.305 m. The corresponding values for the Tilting Flume were 0.304 m and 0.102 m.

All experiments were performed under mobile-bed (live bed) conditions. The mobile bed was in the dune regime for all of the experiments. A photograph of the Main Channel with the dune field (after the removal of the bridge piers and with the flow turned off) is shown in Fig. 1.

Experiments were conducted under the following conditions at the bridge pier:

1. unprotected pier;
2. riprap protection without a geotextile;
3. riprap protection underlain by a geotextile;
4. cable-tied blocks without a geotextile;
5. cable-tied blocks underlain by a geotextile;
6. cable-tied blocks underlain by a geotextile sealed to the pier;
7. grout-filled bags;
8. pier-attached vanes; and
9. submerged permeable sheet piles.

The experimental protocol was designed to model a range of flows up to a severe flood flows. The actual flow conditions varied somewhat from experiment to experiment, but were based on the design conditions outlined below. Let $y_o$ = flow depth, $U$ = flow velocity, $Q$ = flow discharge, $S_w$ = mean flume water surface slope, $d_{50}$ = median sediment grain size, $\rho_s$ = sediment mass density, $\rho$ = water density and $g$ = the acceleration of gravity. The dimensionless Froude number $\boldsymbol{Fr}$ and the dimensionless Shields number $\tau^*$ characterizing sediment mobility are defined below:

$$\boldsymbol{Fr} = \frac{U}{\sqrt{g y_o}} \quad , \quad \tau^* = \frac{y_o S_w}{\left(\frac{\rho_s}{\rho} - 1\right) g d_{50}} \qquad \text{(1a,b)}$$

Each countermeasure was tested using up to four flows, here termed Runs 1 to 4. Run 4 was designed to model an intense flood flow in a medium to large sand-bed stream. The ranges of these flows in the Main Channel were as follows:

| | |
|---|---|
| $y_o$ | 0.15 – 0.6 m; |
| $Q$ | 0.186 – 2.30 m$^3$/s; |
| $U$ | 0.45 – 1.40 m/s; |
| $S_w$ | always 0.002; |
| $\boldsymbol{Fr}$ | 0.37 – 0.58; |
| $\tau^*$ | 0.26 – 1.04. |

The corresponding values for the Tilting Flume were:

| | |
|---|---|
| $y_o$ | 0.05 – 0.20 m; |
| $Q$ | 0.016 – 0.150 m$^3$/s; |
| $U$ | 0.35 – 0.82 m/s; |
| $S_w$ | always 0.004; |
| $\boldsymbol{Fr}$ | 0.47 – 0.58; |
| $\tau^*$ | 0.17 – 0.69. |

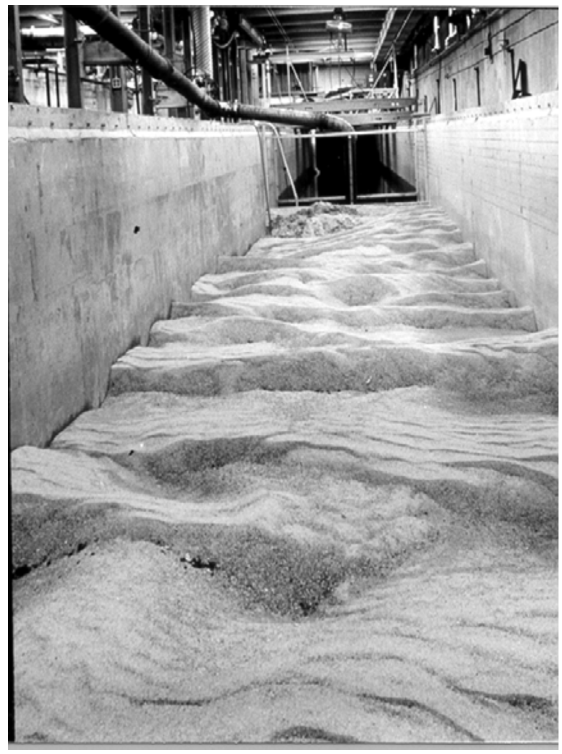

**Fig.1** View of the Main Channel showing a bed covered with dunes. The bridge piers have been removed.

## 3. CHARACTERIZING THE STUDY FLOW REGIME

It can be seen from the above numbers that all the design flows were well into the range of Froude-subcritical flow, with the Froude number $\boldsymbol{Fr}$ never exceeding 0.58. This corresponds to medium to large sand-bed streams, the Froude numbers of which rarely approach the supercritical flow regime.

A regime diagram for rivers can be constructed in terms of a plot of Shields number $\tau^*$ (characterizing sediment mobility) and a particle Reynolds number $\boldsymbol{Re}_p$ defined as

$$
\boldsymbol{Re}_p = \frac{\sqrt{\left(\frac{\rho_s}{\rho} - 1\right) g d_{50}}\ d_{50}}{\nu} \qquad (2)
$$

where $\nu$ denotes the kinematic viscosity of water. The parameter $\boldsymbol{Re}_p$ is a dimensionless surrogate for grain size. Such a regime diagram is shown in Fig. 2.

The details of the regime diagram are explained in the report, Parker et al. (1998). The diagram shows regimes for a) no sediment motion, b) motion but no significant sediment suspension and c) significant suspension. Also shown is a line dividing the dune regime from the ripple regime. Regimes for silt-, sand- and gravel-bed streams are shown. Data for both gravel-bed rivers at bankfull flow ("Brit," "Alta" and "Ida" in the legend) and medium to large sand-bed streams at bankfull flow ("sand sing" and "sand mult" in the legend) are shown.

Medium to large sand-bed streams at flood flow are seen to be in a region where sediment is suspended significantly and the predominant bedform is the dune. This is precisely the region that was modeled in the flume experiments. In the legend, SAFL Main denotes the design conditions in the Main Channel (Runs 1 – 4 are plotted), and SAFL Tilt denotes the design conditions in the Tilting Flume (Runs 2 – 4). The overlap with sand-bed streams at flood stage ensures that the experiments capture the performance of scour protection measures under flood conditions.

The riprap was sized so that it should be barely stable at the conditions of Run 3, but subject to failure at the conditions of Run 4. In this way, it was possible to record the mode of failure of the riprap under flood conditions.

## 4. THE VIDEOS

In the course of conducting the experiments on scour around bridge piers, an extensive set of video images were recorded from inside the four model bridge piers with transparent walls. The video images provide a revealing view of scour processes, and how they interact with countermeasures against scour under the severe conditions characteristics of sand- bed streams in flood. They have been condensed to a single DVD of educational value. The DVD begins with a summary of the experimental conditions. It then provides views looking upstream from inside the bridge piers under the following conditions.

1. **Scour at unprotected piers** The first sequence shows the scour process from inside circular and rectangular bridge piers. The flow conditions are intense, and accurately model flood conditions in sand bed channels. Intense sediment transport and suspension, the intermittent action of the horseshoe vortex, the fluctuating scour and periodically failing avalanche face on the upstream side of the scour hole are vividly rendered. The strong interaction between migrating dunes and the scour hole is illustrated.

2. **Performance of riprap without a geotextile or filter layer at a pier** The images illustrate the tendency for riprap to gradually sink and disperse in response to the effect of migrating dunes, even under conditions for which it is never directly entrained by the flow. Intense leaching of sand from the interstices of the riprap is captured. Failure of the riprap by entrainment is illustrated at very intense flow.

3. **Performance of riprap underlain by a geotextile** The tendency of the geotextile to suppress leaching of sand is illustrated. This notwithstanding, leaching is observed between the geotextile and the face of the pier. Uplift failure of the geotextile is observed at flows sufficiently intense to entrain the riprap. Good anchoring of the geotextile is realized by gradual edge failure of the riprap.

4. **Performance of riprap underlain by a geotextile sealed to the pier** The video images show how such a configuration brings a halt to both sediment leaching and settling of the riprap. The beneficial process of anchoring of the geotextile along its outer edge by settling riprap is illustrated. At a sufficiently intense flow the riprap is plucked away and the geotextile exposed.

5. **Technology for laying a geotextile around a pier at low flow** The outer edge of the geotextile has been weighted and connected to cables. These cables are manipulated by a crane operating from a model bridge pier. The geotextile is gradually extended from the crane, and weighted from behind with dumped riprap. The geotextile is sealed to the pier by means of a cable inside a flexible tube. The chain is tightened and clamped into place.

6. **Performance of cable tied blocks without a geotextile** The video captures leaching of sand from the interstices of the blocks that is sufficiently intense to create a sizable scour hole underneath the block mattress. As a sufficiently high flow the block mattress fails by uplift and is wrapped against the pier. In so far the block mattress falls back into place when the flow is reduced, the video images illustrate a failure that would not easily be detected by inspection after the fact.

7. **Performance of cable tied blocks underlain by a geotextile** The video documents considerably

improved performance, with excellent self-anchoring along the outer edge. Local leaching of sand from the gap between the geotextile and the pier nevertheless causes noticeable settling. At a sufficiently intense flow the block mattress is seen to undergo incipient failure.

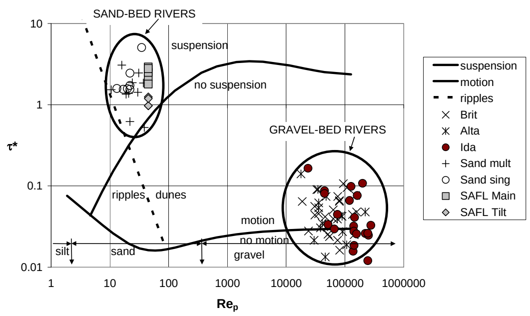


**Fig.2** Regime diagram showing regions for gravel-bed rivers at bankfull flow, sand-bed rivers at bankfull flow and the flow conditions in the Main and Tilting Channel at SAFL used to study bridge scour.

8. **Performance of cable tied blocks underlain by a geotextile sealed to the pier** The excellent performance of this configuration is illustrated. A thin layer of riprap was placed on top of the geotextile along the pier. This riprap is observed to fail at an intense flow, but the block mattress continues to perform well under very adverse conditions.

9. **Grout filled bags** The ease with which these bags slide and disperse, and their lack of flexibility (as compared to angular riprap) is illustrated. Very long grout filled sausages remain stable, but scour readily progresses underneath them due to their lack of flexibility. The geotextile underneath is observed to fail even though the sausages do not move.

10. **Pier-attached vanes** This intriguing concept is shown to offer little protection to bridge piers under mobile bed conditions typical of sand bed rivers in flood. If the scour proceeds below the lowest pier attached to the vane, the resulting scour hole is larger than if there were no vanes attached.

11. **Submerged permeable sheet piles** These devices, placed upstream of bridge piers, are intended to operate on the same principle as snow fences to encourage deposition. Of themselves, they are seen to offer little scour protection under intense flood conditions in sand bed streams. They can, however, help stabilize otherwise undersized riprap around a bridge pier.

## 5. CONCLUSION

The videos provide both the practicing engineer and the engineering student with an eye-opening view of scour around bridge piers under the intense conditions of flood flows in sand-bed streams. Complete details about the experiments and the results they provided can be found in Parker et al. (1998).

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## REFERENCES

1) Parker, G., Toro-Escobar, C. and Voigt, R. L., Jr. : Countermeasures to protect bridge piers from scour, Vol. 2, *Project Report* PR-433, St. Anthony Falls Laboratory, University of Minnesota, Minneapolis, USA, prepared for the National Cooperative Highway Research Board (project NCHRP 24-7), National Research Council, 360 p. 1998.