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MEASURING DEVELOPING SCOUR HOLES IN GRAVEL

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A system for the measuring of developing scour holes at a gravel-embedded 0.20 m diameter circular cylinder is presented. Non-intrusive, high-resolution topographic measurements of developing scour holes were made using a laser distance sensor (LDS) and precision step-motors installed inside the pier. A clear-water experiment was conducted with bed shear stress equal to 95% of the critical bed shear stress for the initiation of sediment motion at the undisturbed plane sediment bed with a d_{50} of 3.25 mm. During the running experiment of 40 hours duration, measurements were taken by the LDS in different azimuthal planes with θ = 0, 30, 60, 90, 135, and 180º in order to study the spatio-temporal variation of geometric properties in developing scour holes. Measurement of maximum scour depth in different azimuthal planes at different time-points during the experiment show that scour started at the cylinder side, progressed faster to the front than to the wake, and surrounded the cylinder after about 5% of experiment time. Slopes of developing scour holes presented three regions with different inclinations, which are attributed to vortex action.

Key Words : *Scour in gravel, Bridge piers, Experimental hydraulics, Laser distance sensor*

1. INTRODUCTION

Scour around bridge piers has been extensively studied in the past. Nevertheless, most of past studies focused on scour in alluvial sand beds. Raikar and Dey (2005a) presented experimental results on scour in uniform gravels, analyzing the effect of gravel size on equilibrium scour depth, while Raikar and Dey (2005b) presented an experimental study on scour in gravels, analyzing the effect of sediment gradation on scour depth. In both mentioned studies, it was concluded that significant differences in scour are expected depending on the sediment type i.e. sand or gravel.

Especially the complete geometry of scour holes, i.e. not only the scour depth at the pier front is a less investigated aspect of bridge hydraulics. Dargahi (1987) described the slopes of a scour-hole based on experiments with sand. In their comprehensive review of the important studies on scour at piers, Hoffmans and Verheij (1997) presented sketches of scour hole topography for equilibrium scour-holes based on very scarce references.

Yanmaz and Köse (2007) presented surface characteristics of scouring at bridge elements. Link (2008) conducted detailed measurements of developing scour holes in coarse sand, providing experimental evidence on the interaction between the horseshoe vortex and the scour slopes.

In this article, a scour experiment in gravel is presented. The experimental data show the topography of developing scour-holes in gravel and highlights the temporal dynamics of scour-hole geometry.

2. EXPERIMENTAL FACILITY

Scour experiments were conducted at the Institute for Hydraulic and Water Resources Engineering of the Darmstadt University of Technology, Germany.

Tests have been conducted in a rectangular flume with glass side-walls, 26 m long, 2 m wide and 1 m deep. A 0.2 m diameter Plexiglas cylindrical pier was mounted in the middle of a working section located 16 m downstream of the flume entrance and having a length of 4 m, width of 2 m and depth of 0.5 m. A false bottom made of concrete plates was installed to avoid the filling of the whole flume with sediment. The plates rested on bricks, 0.5 m above the original flume bottom. To avoid secondary flows, the sides of the working section were coated with absorbing material. The surface of the false bottom at the upstream and downstream of the working section was covered with a 7 cm thick gravel layer, in order to provide homogeneous roughness of the whole channel during the clear-water scour experiments.

The employed bed material was gravel with grain sizes ranging between 2.25 and 4.00 mm and a sediment size for which 50% of the sediment is finer, d50 of 3.25 mm. The geometric standard deviation of the particle sizes was $\sigma_g = \sqrt{d_{84.1}/d_{15.9}} = 1.20$. The natural repose angle of sediment particles ϕ was 30° and the critical shear stress for the initiation of motion of isolated sediment particles was τ_{cr} = 0.205 N/m^2 . Critical shear stress was determined experimentally, from the measured velocity profile as $\tau = \rho u_*^2$. The approaching flow velocity-profile was measured with an acoustic Doppler velocimeter (ADV). The flow depth along the flume was controlled with ultrasonic distance sensors (UDS).

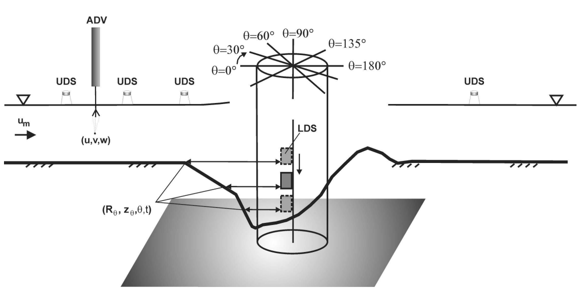

Figure 1. Measuring scheme

Scour-hole radius was measured with a laser distance sensor (LDS) located inside the plexiglas pier. The laser distance sensor has a measurement range of 0.65 m with an accuracy of ±0.30 mm. The sensor was driven in the vertical direction by a step-motor with a precision of ±1/50 mm allowing the recording of vertical profiles in the scour hole. In the radial direction, vertical positioning system was driven by a second step-motor with an accuracy of ±1/100°, allowing the distance sensor to turn around in the scour hole, taking various vertical profiles in different radial directions. The measured radius R_θ, vertical coordinate z_θ, and radial coordinate θ, of the sensor position were registered with a frequency of 70 Hz. Fig. 1 illustrates the measuring scheme.

The presented experiment was conducted over 40 hours with a section-averaged velocity equal to 0.62 m/s and a flow depth of h = 0.30 m. Bed shear stress was equal 95% of the critical bed shear stress for the initiation of sediment motion at the plane sediment bed. Thus, clear water conditions were achieved.

3. PRELIMINARY RESULTS

The presented experiment was stopped after t = 40 hours, when scouring approached equilibrium, i.e. an erosion rate of 1.20 mm per hour. Final maximum scour depth in the scour hole was 31 cm, which is equal to 1.6 times the pier width. During the first 60 min, maximum scour depth in the scour hole moved from azimuthal half-plane with θ = 60° to azimuthal half-plane with θ = 0° as shown in Figure 2, where maximum scour depth in different azimuthal planes with θ = 0, 30, 60, 90,135 and 180° for given times is plotted. At the wake of the pier, a deposition region was observed during the first 15 min, after that time scour surrounded the pier.

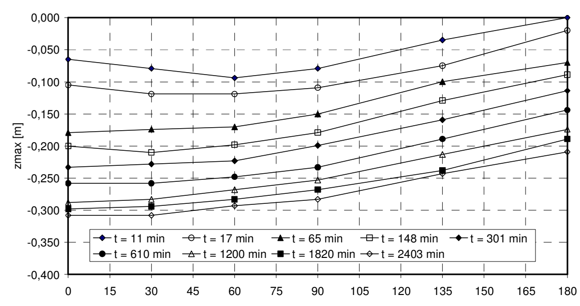

Figure 2. Maximum scour depth in azimuthal planes with θ = 0, 30, 60, 90,135 and 180° after t = 11, 17, 65, 148, 301, 610, 1200, 1820 and 2403 min

Figure 3 shows measured cylindrical coordinates (R, θ, z) of developing scour holes after t = 11, 17, 65, 148, 301, 610, 1200 and 2403 min. Development of scour hole topography is evident. Scouring started very fast at the pier sides, the deepest point being found at θ about 60° during the first 60 min. Later,

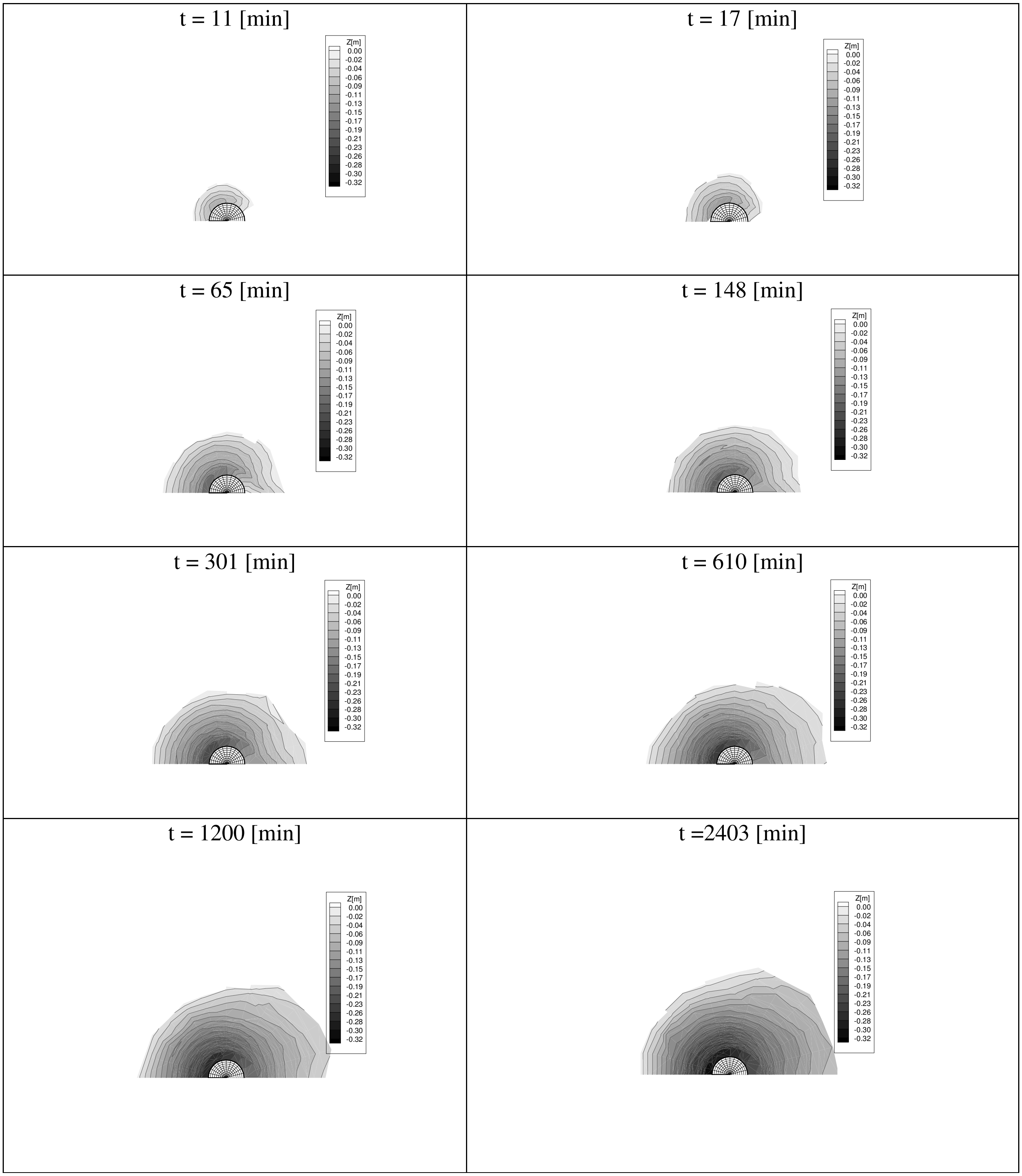

Figure 3. Scour hole topography after t = 11, 17, 65,148, 301, 610, 1200and 2403 min

maximum depth at the pier front approached maximum depth inside the scour-hole with small variation between 0 and 30°. Observed differences in maximum scour depth at azimuthal half-planes with θ = 0 and 30° was negligible during the experiment, with a maximum value of 1.50% at t = 2403 min. The scoured region surrounded the cylinder after 15 min. At the cylinder wake, scouring was delayed with respect to the cylinder front, starting after scour depth at θ = 0° reached approximately 11 cm.

Figure 4 shows developing scour holes on the azimuthal half-planes with θ = 0, 30, 60, 90, 135, and 180°, and t = 11, 17, 65, 148, 301, 610, 1200, 1820, and 2403 min. Scour hole shape remained nearly constant during scour development. The shape consisted of three regions. Close to the cylinder, a ring shaped portion of scour hole is identified. This shape was difficult to measure with the measuring system, thus in Figure 4 the ring shape was interpolated based on our observations. Over this ring, two concave slopes are distinguished in the measured scour hole profiles. At the pier front, on azimuthal half-planes with θ = 0, 30, 60, and 90°, the average slopes of scour-hole sides change from 50 to 38°. At the pier wake, these slopes change with θ. On the azimuthal half-plane with θ = 135o, the average side slopes diminishes, changing from 45° to 25°. On the azimuthal half-plane with θ = 180°, the scour hole present a single average side inclination of 25°.

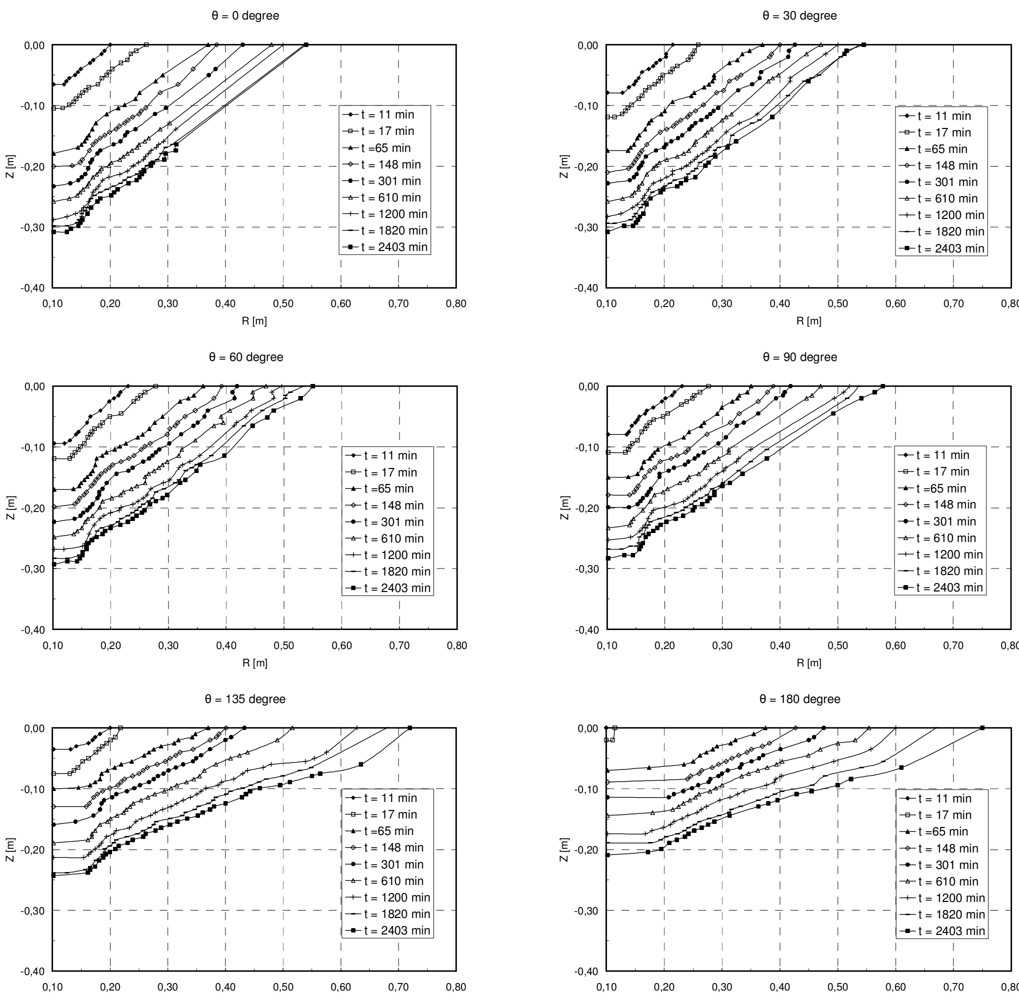

Figure 4. Developing scour holes on the azimuthal half-planes with θ = 0, 30, 60, 90, 135, and 180^{o}, and t = 11, 17, 65, 148, 301, 610, 1200, 1820 and 2403 min.

Scour hole shape and slope break suggest the action of the horseshoe-like vortices with different strengths. Vortex strength being lower to the upper part of the scour hole. Counterclockwise vortex rotation contributes to side stabilization, explaining the existence of sides with a higher inclination than the natural repose angle.

4. CONCLUSION

A system for the measuring of developing scour holes at a gravel-embedded 0.20 m diameter circular cylinder was presented. Measurements were performed in a non-intrusive manner by using a laser distance sensor (LDS) and precision step-motors installed inside the pier.

A fourty hours duration, clear-water scour experiment in gravel with d_{50} equal 3.25 mm was presented, in order to analyze the geometry of developing scour holes.

Scour started at the cylinder side, progressed faster to the front than to the wake, and surrounded the cylinder after about 5% of experiment time.

Slopes of developing scour holes presented three regions with different inclinations, which supported the hypothesis of a scour mechanism based on horseshoe vortex interaction with side-slides.

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