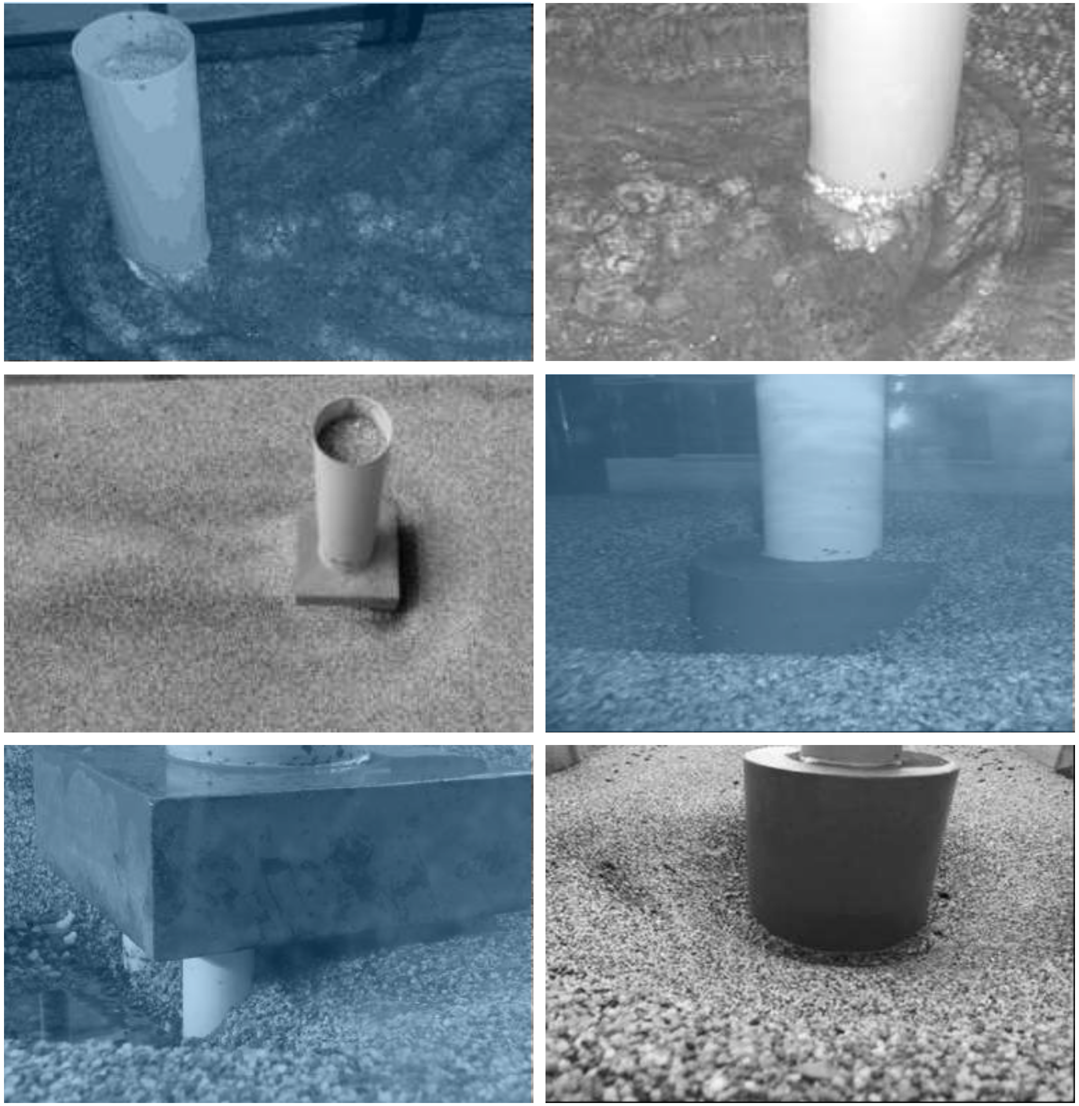


# Temporal Variation of Local Scour at Bridge Piers with Complex Geometries

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# Exposure of bridge foundations due to

## long-term degradation

## local scour during runoff events

# Some literature papers

An early investigation on local scour at non-uniform piers was made by **Chabert and Engeldinger** (1956). They carried out a few laboratory experiments testing a cylindrical pier founded on a larger cylindrical caisson.

**Parola *et al*.** (1996) showed that scour depth is highly sensitive to changes in foundation geometry and position. The foundation tends to alleviate scour when placed below the streambed.

**Melville and Raudkivi** (1996) presented an experimental investigation of local scour at non-uniform cylindrical piers (i.e. a cylinder of diameter $D$ founded on a larger cylinder of diameter $D^*$). The concept of an effective pier size is introduced and various design relationships are presented.

**Coleman (2005)** presented a new methodology to predict local scour depth for varying pile cap elevation. The effects of the upstream pile cap extension were also considered, noting such an extension acts to reduce scour.

**Ashtiani *et al*.** (2010) carried out 70 experiments considering a variety of configuration, including different sizes and shapes of complex piers.

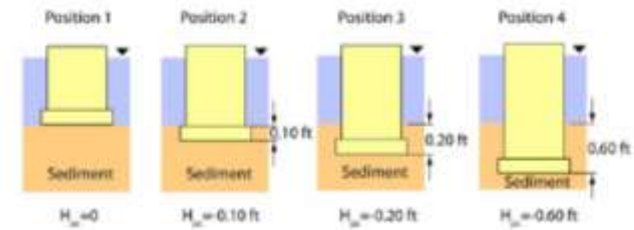



Figure 4-24 Position of the structures in Sterling Jones' experiments.

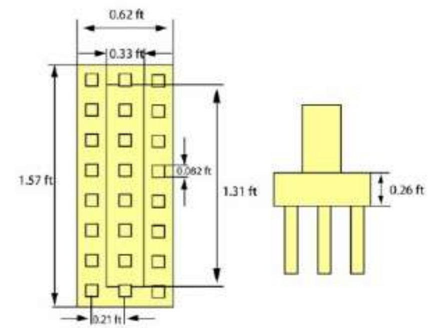



Figure 4-28 Plan and elevation view of model complex pier 3 (Type C, All dimensions are in feet). [Coleman's experiments]

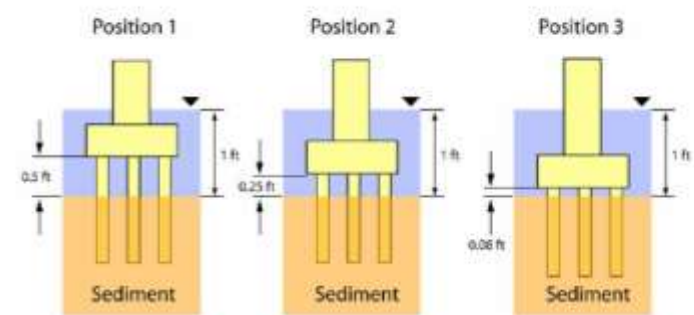


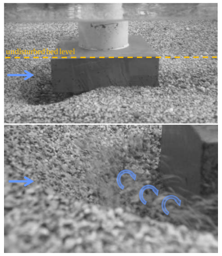

Figure 4-31 Position of the piers in Sheppard's experiments.

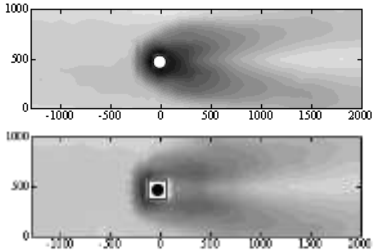
*from FDOT – Bridge Scour Manual, 2005*

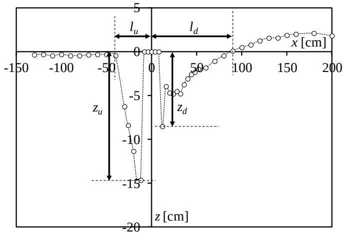
# Objectives of the present study

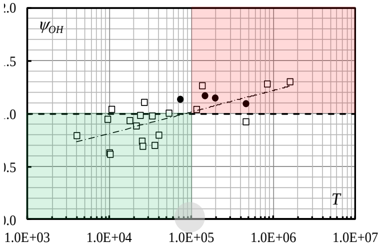
analysis of the temporal and spatial evolution of local bed morphology around piers founded on piles (when the top elevation of the pile cap is flush with the undisturbed bed level), based on a number of long-duration laboratory experiments

analysis of differences with local scour at uniform cylindrical piers



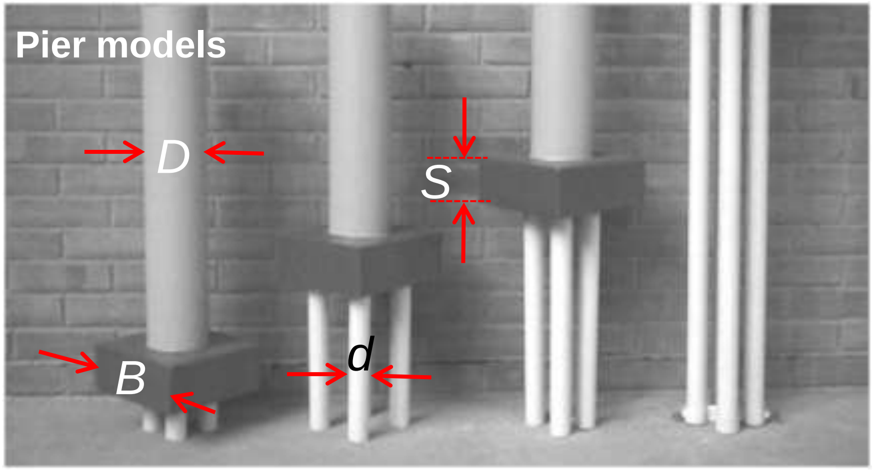




# Experimental Stand and Pier Models

experiments were performed in a 1 m wide and 20 m long rectangular straight channel at the University of Basilicata, Italy




$D$ = 0.12 m $B$ = 0.24 m $S$ = 0.08 m $d$ = 0.04 m

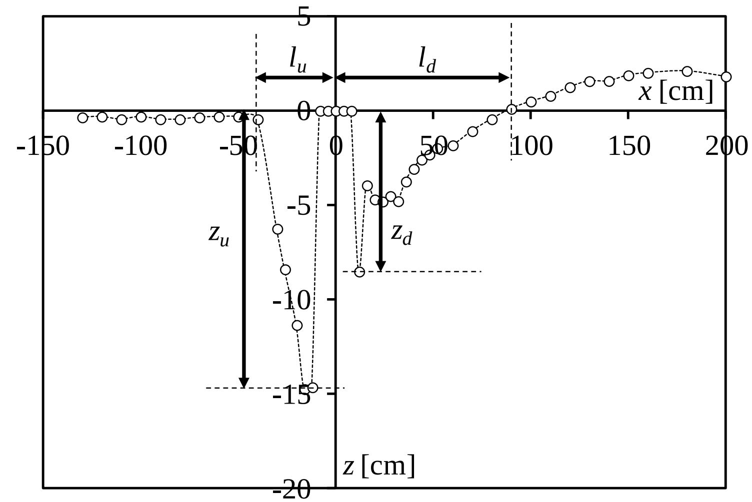

$d_{50}$ = 1.7 mm $\sigma = (d_{84}/d_{16})^{1/2}$ = 1.5 $\rho$ = 2650 kg/m$^3$

# Test conditions and scour hole characteristics

uniform cylindrical pier

| Test | $Q$ [m³/s] | $h_o$ [m] | $F_d$ [-] | $F_{di}$ [-] | $z_u$ [m] | $z_d$ [m] | $l_u$ [m] | $l_d$ [m] | $W$ [dm³] | $t$ [h] |
|---|---|---|---|---|---|---|---|---|---|---|
| CP0 | 0.048 | 0.10 | 2.89 | 2.83 | 0.171 | 0.015 | - | - | - | 12 |
| | | | | | 0.187 | 0.017 | - | - | - | 24 |
| | | | | | 0.188 | 0.017 | - | - | - | 32 |
| | | | | | 0.192 | 0.017 | 0.50 | 1.10 | 192 | 76 |
| CP1 | 0.048 | 0.10 | 2.89 | 2.83 | 0.163 | 0.064 | 0.40 | 1.00 | 147 | 19 |
| CP2 | 0.048 | 0.10 | 2.89 | 2.83 | 0.162 | 0.084 | 0.40 | 1.10 | 147 | 76 |
| CP3 | 0.042 | 0.11 | 2.30 | 2.86 | 0.090 | 0.034 | 0.40 | 0.60 | 26 | 3 |
| | | | | | 0.147 | 0.074 | 0.50 | 0.85 | 61 | 23 |
| | | | | | 0.172 | 0.140 | 0.50 | 1.10 | 138 | 143 |
| | | | | | 0.183 | 0.161 | 0.50 | 1.15 | 163 | 271 |
| CP4 | 0.070 | 0.15 | 2.81 | 2.98 | 0.097 | 0.020 | 0.30 | 0.32 | 22 | 1 |
| CP5 | 0.070 | 0.15 | 2.81 | 2.98 | 0.130 | 0.036 | 0.55 | 1.00 | 60 | 4 |
| CP6 | 0.060 | 0.15 | 2.41 | 2.98 | 0.113 | 0.041 | 0.45 | 0.95 | 55 | 2 |
| | | | | | 0.132 | 0.067 | 0.50 | 1.00 | 61 | 5 |
| | | | | | 0.128 | 0.069 | 0.50 | 1.00 | 65 | 10 |
| CP7 | 0.060 | 0.18 | 2.01 | 3.05 | 0.055 | 0.000 | 0.30 | 0.00 | 9 | 2 |
| | | | | | 0.071 | 0.000 | 0.30 | 0.00 | 10 | 5 |
| | | | | | 0.080 | 0.047 | 0.30 | 0.20 | 10 | 8 |
| CP8 | 0.090 | 0.21 | 2.58 | 3.11 | 0.126 | 0.038 | 0.40 | 0.65 | 37 | 2 |
| | | | | | 0.144 | 0.061 | 0.40 | 0.85 | 51 | 5 |
| | | | | | 0.148 | 0.085 | 0.45 | 0.90 | 53 | 7 |
| CP9 | 0.100 | 0.17 | 3.55 | 3.03 | 0.124 | 0.069 | 0.40 | 0.60 | 75 | 2 |
| | | | | | 0.153 | 0.057 | 0.40 | 0.60 | 115 | 5 |
| | | | | | 0.160 | 0.058 | 0.40 | 0.70 | 116 | 7 |

nearly live-bed regime




$Q$ = discharge

$h_o$ = approach flow depth

$F_d$ = densimetric Froude number

$F_{di}$ = inception densimetric Froude number

$z$ = axial scour depth

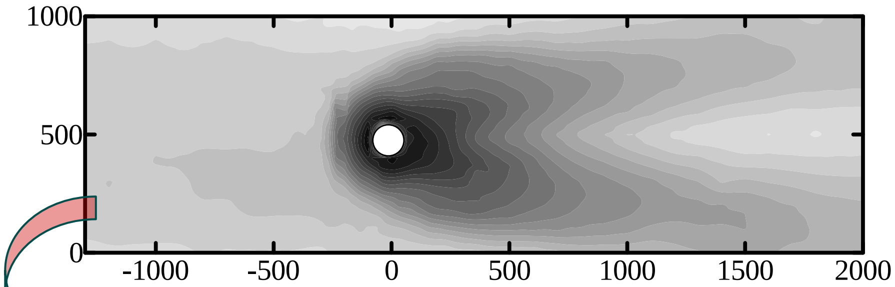
$l$ = axial length of the scour hole

$W$ = scour hole volume

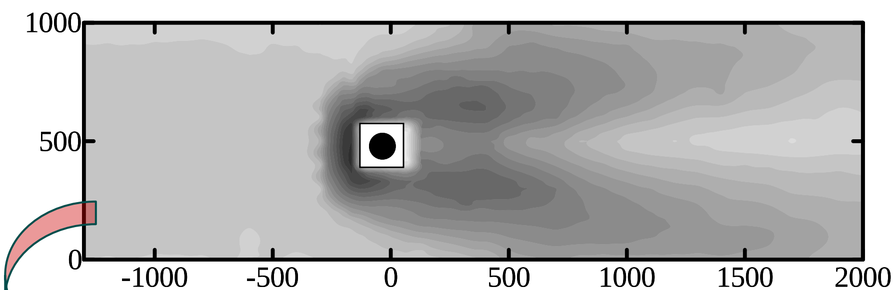
$t$ = time

# Some contour maps

Contour maps for runs CP0 (top) and CP2 (bottom) at $t$ =76 h

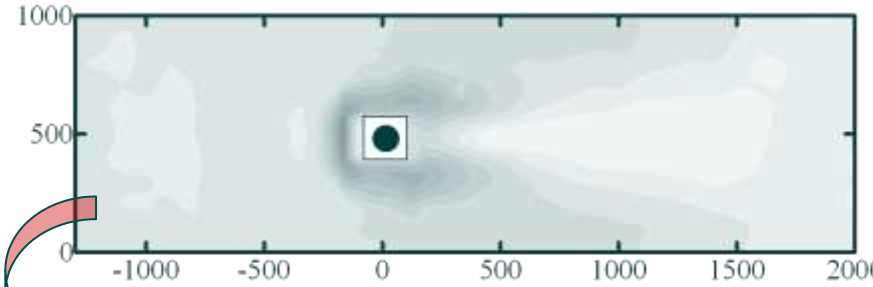



| $z_u$ [m] | $z_d$ [m] | $l_u$ [m] | $l_d$ [m] | $W$ [dm$^3$] |
|---|---|---|---|---|
| 0.192 | 0. 170 | 0.50 | 1.10 | 192 |

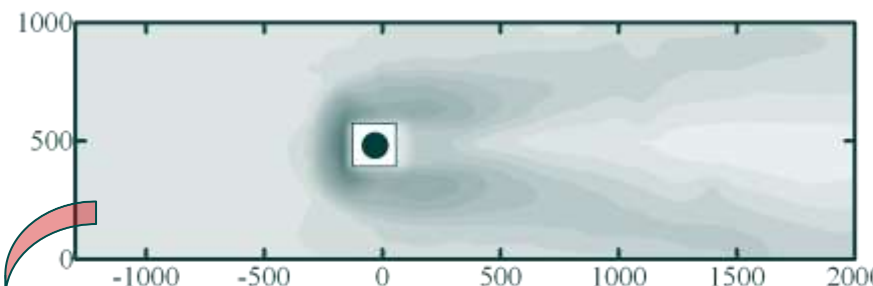



| $z_u$ [m] | $z_d$ [m] | $l_u$ [m] | $l_d$ [m] | $W$ [dm$^3$] |
|---|---|---|---|---|
| 0.162 | 0.084 | 0.40 | 1.10 | 147 |

Contour maps for runs CP4 at $t$ =1 h (top) and CP5 at $t$ =4 h (bottom)

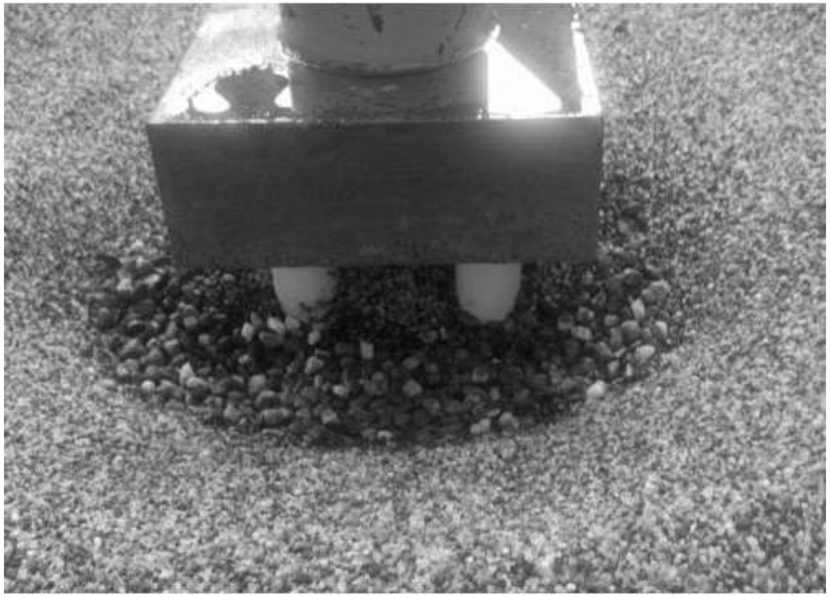


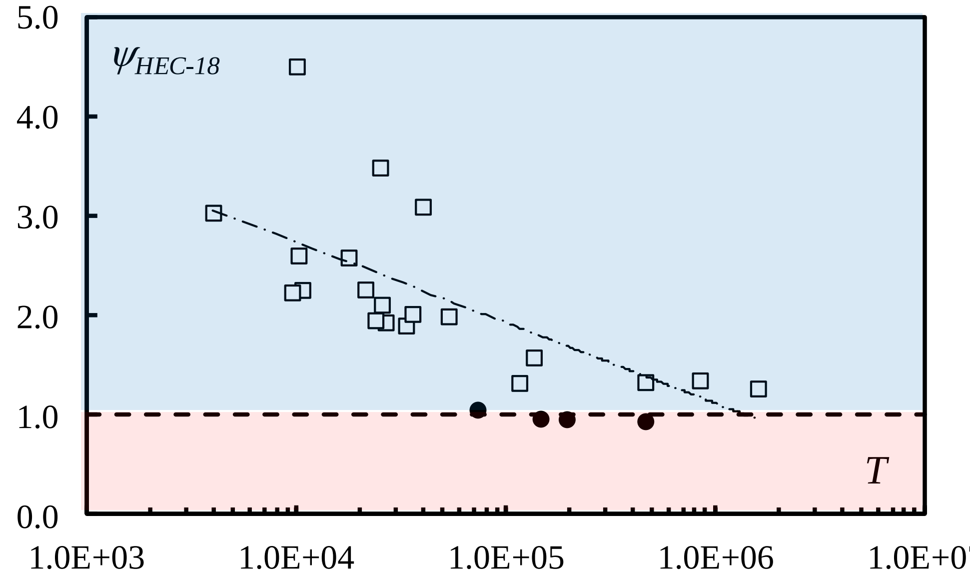

| $z_u$ [m] | $z_d$ [m] | $l_u$ [m] | $l_d$ [m] | $W$ [dm$^3$] |
|---|---|---|---|---|
| 0.097 | 0. 020 | 0.30 | 0.32 | 22 |




| $z_u$ [m] | $z_d$ [m] | $l_u$ [m] | $l_d$ [m] | $W$ [dm$^3$] |
|---|---|---|---|---|
| 0.130 | 0.036 | 0.55 | 1.00 | 60 |

# Comparison with HEC-18 approach






The HEC-18 approach implies the superposition of three scour components which include the scour depths caused by the pier stem, the pile cap, and the pile group. In particular:

$$\frac{z_{pier}}{h_o} = K_{hpier}\left[2.0K_1K_2K_3K_4\left(\frac{D}{h_o}\right)^{0.65}\left(\frac{V}{\sqrt{gh_o}}\right)^{0.43}\right]$$

$$\frac{z_{pile\,cap}}{h_f} = K_w\left[2.0K_1K_2K_3K_4\left(\frac{B}{h_f}\right)^{0.65}\left(\frac{V_f}{\sqrt{gh_f}}\right)^{0.43}\right]$$

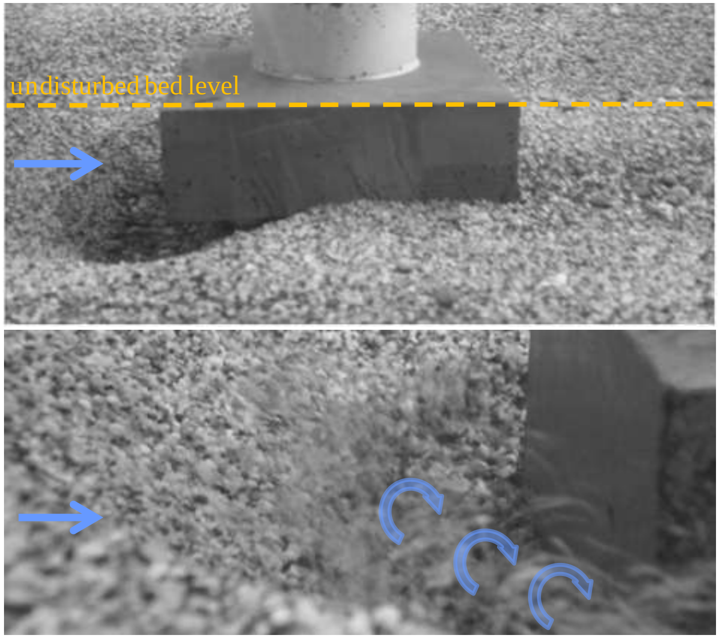
$\Psi_{HEC-18}$ is the ratio of computed to observed scour depths according to HEC-18 approach for complex piers

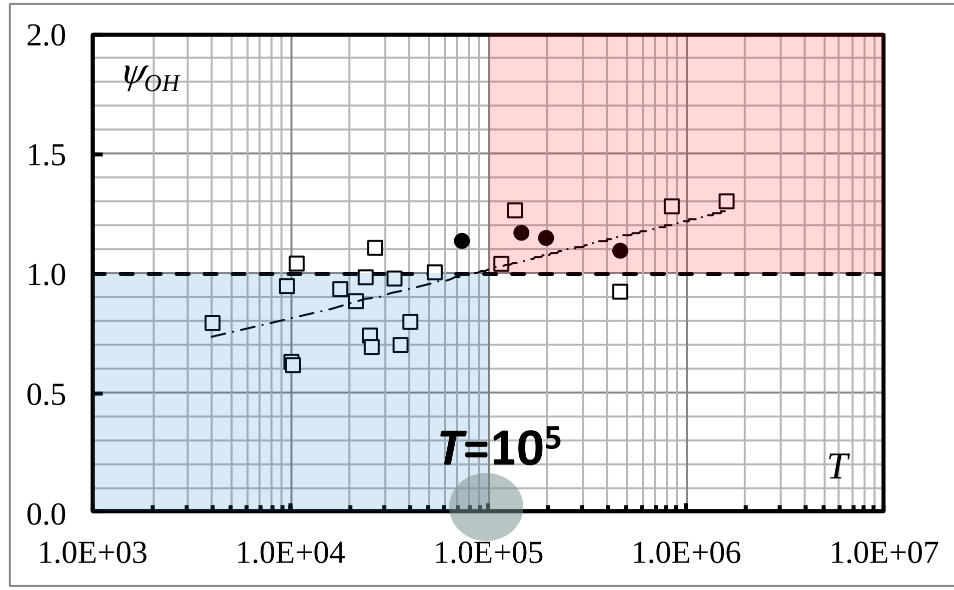
● Data for run CP0 (uniform cylindrical pier)

- - - - - line of perfect agreement

- · - · - regression line

# Temporal variation of scour depth




$$Z = z / L_R = 0.068\sigma^{-1/2}\mathsf{F}_d^{\,1.5}\log T$$

[ Oliveto and Hager, JHE 2002]

$\Psi_{OH}$ is the ratio of observed to computed scour depths according to Oliveto and Hager (2002) approach for uniform cylindrical piers

$L_R = D^{2/3}h_0^{1/3}$ reference length

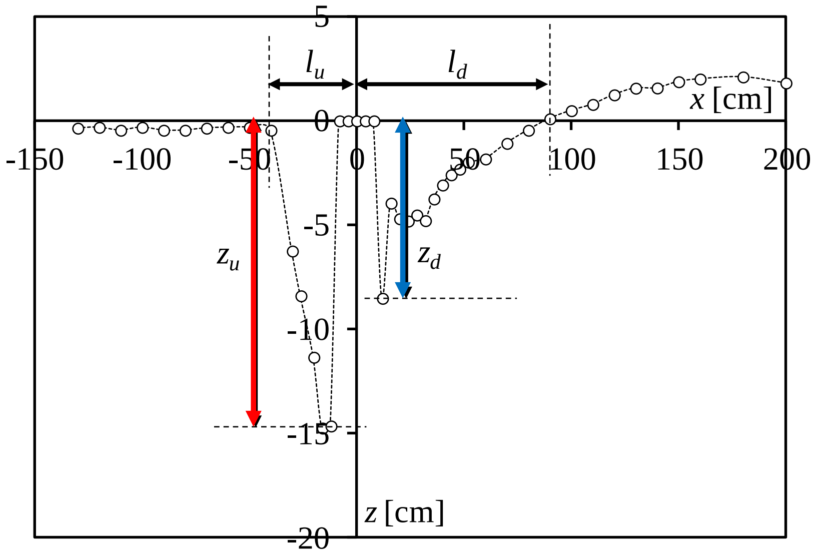
$T = [\sigma^{1/3}(g'd_{50})^{1/2}/L_R]t$ relative time

- Data for run CP0 (uniform cylindrical pier)

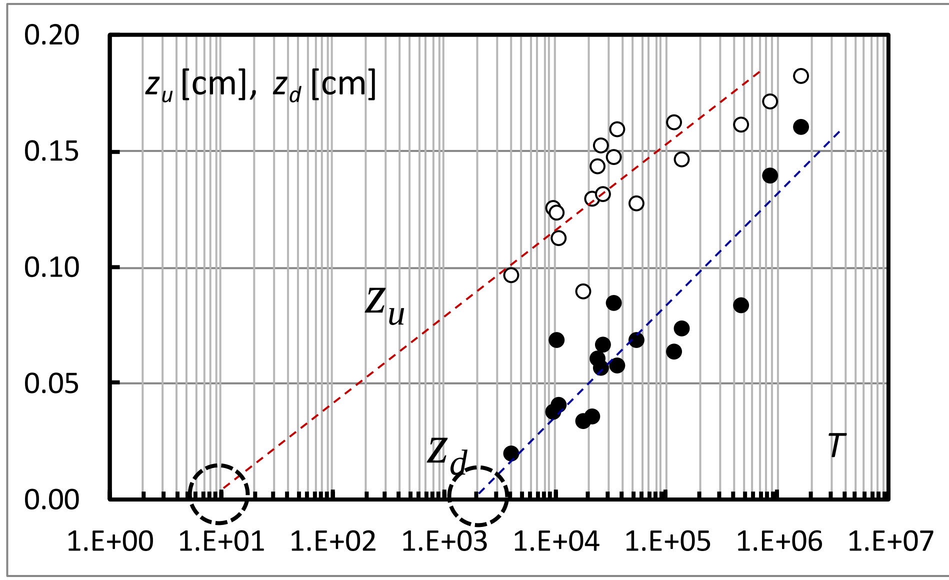
- - - - - line of perfect agreement

- · - · - regression line

# Scour hole features




**Axial scour profile at *t* =7h for run CP8 and definition of main characteristics of the scour hole**




$l_u$ was found independent of $F_d$ and $T$

$$\frac{l_d}{D^{2/3}h_0^{1/3}} \propto F_d^{0.50} T^{0.22}$$ $r^2 = 0.60$

$$\frac{z_u}{D^{2/3}h_0^{1/3}} \propto F_d^{0.75} T^{0.18}$$ $r^2 = 0.80$

$$\frac{z_d}{D^{2/3}h_0^{1/3}} \propto F_d^{0.35} T^{0.33}$$ $r^2 = 0.87$

Scour depth at pile cap front starts at $T$ around 10 while scour at the rear of the pile cap starts later, at $T$ around $2{\cdot}10^3$

○ scour depths at the front of the pile cap

● scour depths at the rear of the pile cap

- - - - - regression lines

# Conclusions

Laboratory experiments on local scour around a pier with a complex geometry were carried out. Runs lasted from 0.75 up to 271 hours to explore the temporal variation of the local bed morphology. The main results can be summarized as follows:

i. observed data were compared to the predicted values according to HEC-18 approach for complex pier foundations. Results reveal that the HEC-18 approach provides a suitable method for scour prediction at the equilibrium stage. Conversely, it leads to significant overestimations when more realistic conditions of unsteady flow are considered

ii. observed data were also compared with the predicted values for uniform cylindrical piers. Results reveal that the shielding effect by the pile cap occur for *T* around $10^5$; and

iii. axial upstream scour length rapidly attains its equilibrium value while the axial downstream scour length depends on $F_d$ and *T*. Moreover, scour at the rear of the pile cap starts later compared to the pier front, but develops at a faster rate.