Lança et al. (2013) are incapable of accurately describing the effect of sediment coarseness. Comparatively, the equations of Lee and Sturm (2009) show better agreement with data from the present study. This feature is attributed to the structural complexity and corresponding flow complexity around complex pier. Thus, more study on the flow field is needed.

(4) For skewed complex piers where the pile group is exposed after scouring, the maximum scour depth usually occurs at the downstream end of the upstream row of piles; when the pier is aligned to flow, the maximum scour depth occurs at the two upstream piles, or under the front edge of the pile-cap, according to the degree of the pile-cap's exposure after scouring; when the pier is perpendicular to the flow, the maximum scour depth usually occurs at the middle two piles of the upstream row. For piers where the pile-cap is partially buried after scouring, the maximum scour depth normally occurs in front of the pile-cap (aligned pier) or at the side of the pile-cap (skewed pier). If the pile-cap is completely buried after scouring, namely the column-only situation, the maximum scour depth occurs at one of the corners of the upstream flank of the column. This case typically shows the deepest scour.

**ACKNOWLEDGEMENTS**

The leading author acknowledges the financial support from China Scholarship Council (CSC), the valuable suggestions for the manuscript from Dr Keith Adams, and the help from Mr. Chunguang Yuan in conducting the experiments.

**NOTATION**

$b_c$ = width of column;
$b_{pc}$ = width of pile-cap;
$b_{pg}$ = diameter of piles;
$B$ = flume width;
$d_s$ = scour depth;
$d_{se}$ = equilibrium scour depth;
$d_{sm}$ = measured scour depth at the end of test;
$d_{sme}$ = equilibrium scour depth calculated by S/M method using 30 hours data;
$d_{50}$ = median diameter of sediment particles;
$D$ = pier width;
$D_e$ = equivalent width of complex pier calculated by FDOT method;
$f_{cb}$ = pile-cap extension in lateral direction;
$f_{cl}$ = pile-cap extension in longitudinal direction;
$H_c$ = pile-cap elevation, e.g. the height of column base to the bed, positive when above the bed;
$l_c$ = length of column;
$l_{pc}$ = length of pile-cap;
$S_m$ = longitudinal pile row spacing ;
$S_n$ = lateral pile row spacing;
$t_d$ = test duration;
$T$ = thickness of pile-cap;
$U$ = depth-averaged mean approach flow velocity;
$U_c$ =mean critical velocity for incipient motion of bed sediment, depth-averaged;
$y_0$ = flow depth;
$\alpha$ = skew angle to flow of pier;
$\sigma_g$ = geometric standard deviation of sediment size distribution.

**REFERENCES**

Amini, A., Melville, B. W. & Ali, T. M. (2014). Local Scour at Piled Bridge Piers Including an Examination of the Superposition Method. *Canadian Journal of Civil Engineering*, 41(5), 461-471.

Arneson, L. A., Zevenbergen, L. W., Lagasse, P. F. & Clopper, P. E. (2012). *Evaluating Scour at Bridges (HEC-18)*. Technical Rep. No. HIF-12-003, Federal Highway Administration, Washington, DC.

Ataie-Ashtiani, B., Baratian-Ghorghi, Z. & Beheshti, A. A. (2010). Experimental Investigation of Clear-Water Local Scour of Compound Piers. *Journal of Hydraulic Engineering*, 136(6), 343-351.

Ballio, F., Teruzzi, A. & Radice, A. (2009). Constriction Effects in Clear-Water Scour at Abutments. *Journal of Hydraulic Engineering*, 135(2), 140-145.

Breusers, H. N. C. & Raudkivi, A. J. (1991). *Scouring*. Rotterdam: Balkema.

Coleman, S. E. (2005). Clearwater Local Scour at Complex Piers. *Journal of Hydraulic Engineering*, 131(4), 330-334.

Ferraro, D., Tafarojnoruz, A., Gaudio, R. & Cardoso, A. H. (2013). Effects of Pile Cap Thickness on the Maximum Scour Depth at a Complex Pier. *Journal of Hydraulic Engineering*, 139(5), 482-491.

 

Friedrich, H. (2010). Evaluation of Statistical Analysis Techniques for Developing Bedforms Recorded In 3D, *Doctoral Dissertation*. University of Auckland.

Grimaldi, C. & Cardoso, A. H. (2010). Methods for Local Scour Depth Estimation at Complex Bridge Piers. *In Procedings of 1st IAHR European Division Congress*.

Jones, J. S., Kilgore, R. T. & Mistichelli, M. P. (1992). Effects of Footing Location on Bridge Pier Scour. *Journal of Hydraulic Engineering*, 118(2), 280-290.

Jones, J. S. & Sheppard, D. M. (2000). Local Scour at Complex Pier Geometries. *In Pproceedings of the ASCE 2000 Joint Conference on Water Resources Engineering and Water Resources Planning and Management*.

Kothyari, U. C. & Kumar, A. (2012). Temporal Variation of Scour around Circular Compound Piers. *Journal of Hydraulic Engineering*, 138(11), 945-957.

Lança, R. M., Fael, C. S., Maia, R. J., Pêgo, J. P. & Cardoso, A. H. (2013). Clear-Water Scour at Comparatively Large Cylindrical Piers. *Journal of Hydraulic Engineering*, 139(11), 1117-1125.

Laursen, E. M. & Toch, A. (1956). *Scour Around Bridge Piers and Abutments*, Bulletin No.4, Iowa Highways Research Board, Ames, IA.

Lee, S. O. & Sturm, T. W. (2009). Effect of Sediment Size Scaling on Physical Modeling of Bridge Pier Scour. *Journal of Hydraulic Engineering*, 135(10), 793-802.

Lu, J. Y., Shi, Z. Z., Hong, J. H., Lee, J. J. & Raikar, R. V. (2010). Temporal Variation of Scour Depth at Nonuniform Cylindrical Piers. *Journal of Hydraulic Engineering*, 137(1), 45-56.

Melville, B. W. (1997). Pier and Abutment Scour: Integrated Approach. *Journal of Hydraulic Engineering*, 123(2), 125-136.

Melville, B. W. & Chiew, Y. M. (1999). Time Scale for Local Scour at Bridge Piers. *Journal of Hydraulic Engineering*, 125(1), 59-65.

Melville, B. W., & Raudkivi, A. J. (1996). Effects of Foundation Geometry on Bridge Pier Scour. *Journal of Hydraulic Engineering*, 122(4), 203-209.

Moreno, M., Maia, R., & Couto, L. (2015). Effects of Relative Column Width and Pile-Cap Elevation on Local Scour Depth around Complex Piers. *Journal of Hydraulic Engineering*, 142(2), 1-9.

Moreno, M., Maia, R. & Couto, L. (2016a). Prediction of Equilibrium Local Scour Depth at Complex Bridge Piers. *Journal of Hydraulic Engineering*, 142(11), 1-13.

Moreno, M., Maia, R., Couto, L. & Cardoso, A. (2012). Evaluation of Local Scour Depth around Complex Bridge Piers. *Proceedings of River Flow 2012*, 2, 935-942.

Moreno, M., Maia, R., Couto, L. & Cardoso, A. (2014). Contribution of Complex Pier Components on Local Scour Depth. In *Proc. 3rd IAHR Europe Congress*.

Moreno, M., Maia, R., Couto, L. & Cardoso, A. H. (2016b). Subtraction Approach to Experimentally Assess the Contribution of the Complex Pier Components to the Local Scour Depth. *Journal of Hydraulic Engineering*, 06016030.

Parola, A. C., Mahavadi, S. K., Brown, B. M. & El Khoury, A. (1996). Effects of Rectangular Foundation Geometry on Local Pier Scour. *Journal of Hydraulic Engineering*, 122(1), 35-40.

Sheppard, D. M. & Glasser, T. (2009). Local Scour at Bridge Piers with Complex Geometries, In Contemporary Topics in In Situ Testing, Analysis, and Reliability of Foundations. *International Foundation Congress and Equipment Expo 2009,* ASCE, 506-513.

Sheppard, D. M., Odeh, M. & Glasser, T. (2003). Large Scale Clear-Water Local Pier Scour Experiments. *Journal of Hydraulic Engineering*, 130(10), 957-963.

Sheppard, D. M. & Renna, R. (2010). *Bridge scour manual*. Florida Department of Transportation, Florida.

Yalin, M. S. (1972). *Mechanics of Sediment Transport*. Pergamon Press.

Zhao, G. & Sheppard, D. M. (1998). The effect of flow skew angle on sediment scour near pile groups. *In Stream Stability and Scour at Highway Bridges: Compendium of Stream Stability and Scour Papers Conference, Sponsored by the Water Resources Engineering (Hydraulics) Division of the American Society of Civil Engineers* (pp. 377-391). ASCE.

 