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Local Scour Depth Estimation around Complex Bridge Pier

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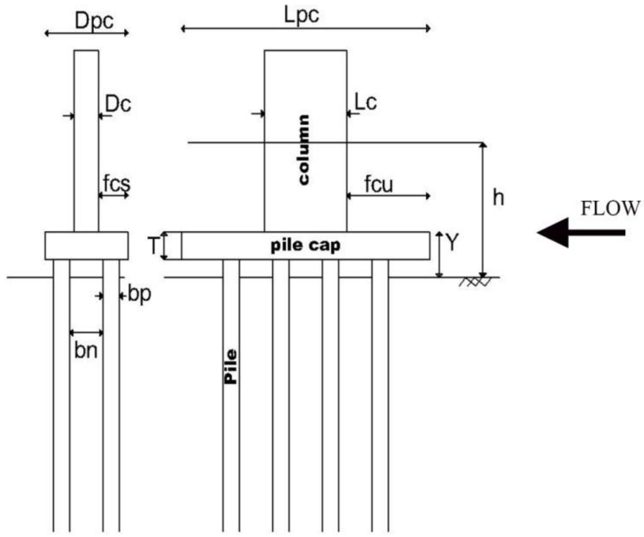
Abstract

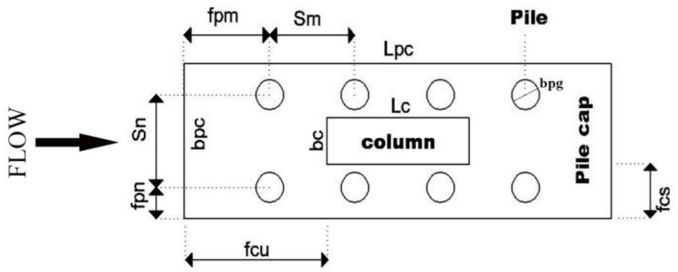
Despite of numerous empirical formulas have been presented to estimate equilibrium scour depth around complex bridge piers, there may no general formula that satisfies all conditions. It may happened because, existing equation are based on dimensional analysis and data correlation of laboratory experiments which do not always produce reasonable results for field conditions. Hence, they mostly give conservative results. This study assembled 750 laboratory data around complex bridge pier. In addition, the accuracy of recent commonly methods for local scour depth estimation around complex bridge pier were evaluated.
Keywords: Complex bridge piers, Local scour, Empirical formula, Laboratory data, Scour depth estimation.

1. INTRODUCTION

When a stream is partially obstructed by a bridge pier, flow pattern around the pier changes significantly. Bridge pier produces an adverse pressure gradient just upstream. Besides, pier upstream boundary layer undergoes a three-dimensional separation. Shear stress distribution around the pier drastically changes due to formation of a horseshoe vortex, resulting in a scour formation hole around the pier, which in turn, changes flow pattern and shear stress (Kothyari et al. 1992).
For many years bridge pier scour problem were limited to a single piles and uniform piers (Melville 1997, Melville and Sutherland 1988). Recently, for economic reasons, complex bridges piers design were encouraged. Complex pier being constructed by a pier column that rests on a foundation or a pile cap supported by a pile group as shown with more detail by Fig. 1. In late 90's, local scour around non-uniform and complex piers has been investigated by Parola et al. (1996), Melville and Raudkivi (1996), Melville and Coleman (2000), Richardson and Davis (2001), Sheppard et al. (2004), Coleman (2005), and Ataie-Ashtiani et al. (2010). Complex pier scour depth is estimated by following methods as: (1) Federal Highway Administration (HEC-18) procedure (Richardson and Davis 2001) in that each element effect is determined separately, then they summed up to compute total scour depth. (2) Sheppard et al. (2004) assumed that each of the complex pier elements may be replaced by a single pile with circular cross section. Equivalent diameter is summed up to calculated total scour depth. (3) Coleman (2005) proposed a method for complex pier scour depth prediction by using an equivalent pier diameter. He considered five different pile cap elevation and linear varies of scour depth. Ataie-Ashtiani et al. (2010) have adjusted both HEC-18 and Coleman (2005) methods by correction factors to better data curve fitting. The main objective of this study is to investigate the accuracy of more recent methods to evaluate local scour depth around complex bridge pier scour. For this purpose, 637 data set were collected from previous study and the predicted scour depth compared with observed scour depth to evaluate the efficiency of the commonly methods. And also, collected experimental data by authors were added to above mentioned data.



a. Side View; view in flow line (right) and view normal to the flow (left)



b. Plan View; including complex pier configuration

Figure 1. Complex pier geometry (a. Side View, b. Plan View)

2. Experimental Set up

In order to measure effects of geometric parameters on complex pier scour depth, 82 experiments were designed and performed. For this purpose, experiments were performed over four pile cap elevations with different cases of pile cap upstream extension, pile group arrangement, and pile group upstream extension. In addition, effect of pile cap thickness on the maximum scour depth was investigated. Efforts were made to find the pile cap elevation at which the cap was undercut and the piles were exposed to the flow.

The experiments were conducted in a concrete flume with 21.85-m long, 0.77-m wide and 0.6-m deep at Shahid Bahonar University, Kerman, Iran. Experiments were designed to allow only local scour development around complex pier model. Complex pier model was constructed with white nylon. The model includes a rectangular cross section column, a rectangular cross section pile cap, and a group of circular cross section piles. These parts were assembled together by pressing on predicted pre-drilled hole. The models configurations geometric parameters are defined as follows (Fig. 1a,b and Table 1):

- Rectangular cross section column with specification of, column width, D_c, column length, L_c;
- Rectangular cross section pile cap, pile cap width, D_{pc}, pile cap length, L_{pc}, pile cap thickness, T; and
- The cylindrical piles, pile diameter, b_p=2 cm, number of piles in flow line, m, number of piles transversal to the flow, n, pile spacing distance, S_m, and pile spacing width, S_n; and the subscript c and pc are for

column and pile cap respectively. Models constant geometric parameters are given in Table 1 with more details.

Complex pier models placed in a sediment recess box center, which was located at 15 m from flume inlet. The recess box was filled with uniform sand with specification of median size d_{50}= 0.71 mm and geometric standard deviation, σ_g= 1.135. Prior to each test, the sand bed was leveled and the flume carefully filled with flowing water, it is tried to do not disturb the planner bed.

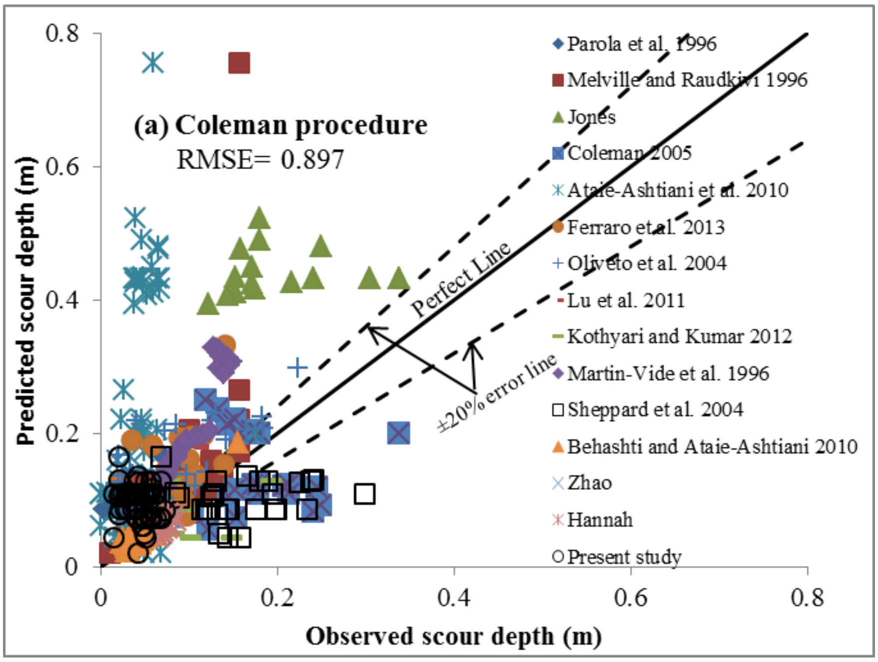
Flow depth was controlled with a variable height sharp edged weir located at the flume downstream end. Flow discharge was controlled and regulated by upstream valves. In clear-water condition, the flow depth was adjusted so as, the ratio of the critical flow velocity to the critical shear velocity was less than unity (U/U_c<1). The flume water was collected in a downstream reservoir by dimension of 3.95-m long, 3.95-m width, and 3.24-m deep, and recirculating by return system including a pump, pipes and still basin.

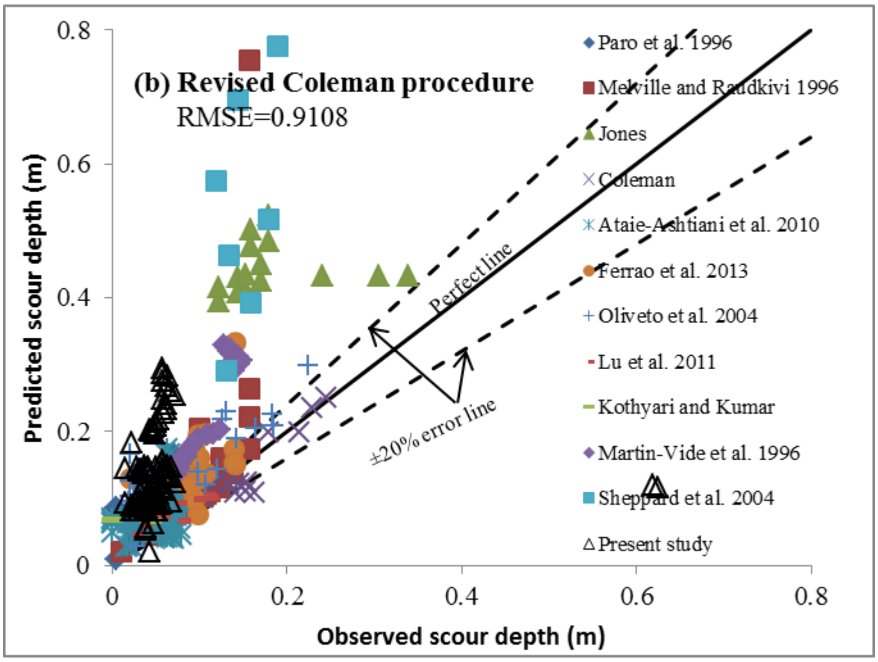
Table 1. Pier Geometry Characteristics

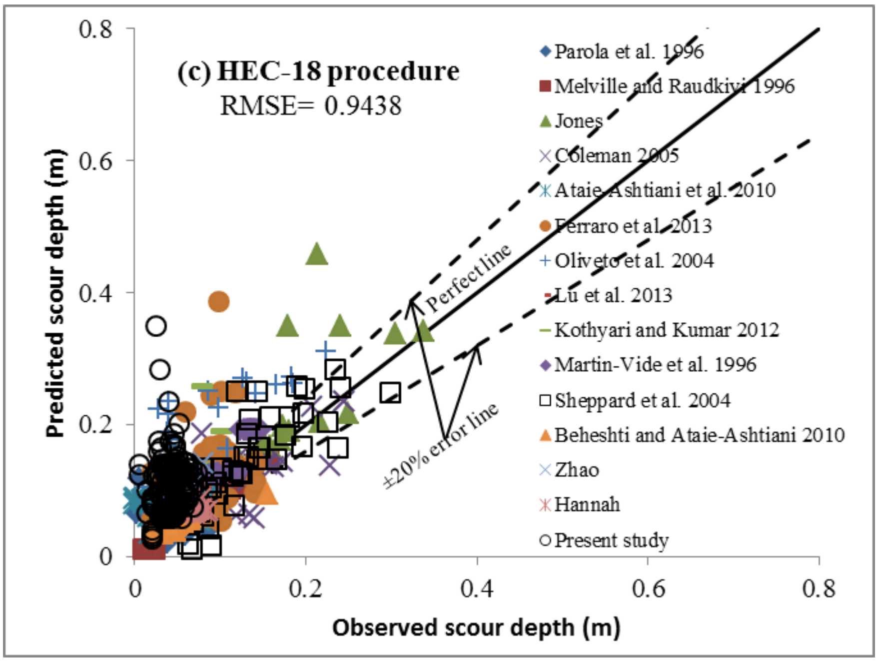
Parameter definition	Model	I	II	III	IV	V	VI
column width	D_c(m)	0.03	0.03	0.03	0.03	0.03	0.03
column length	L_c(m)	variable	0.08	0.14	0.20	0.275	0.275
pile cap width	D_{pc}(m)	0.10	0.10	0.10	0.10	0.10	0.10
pile cap length	L_{pc}(m)	0.30	0.18	0.24	variable	0.30	0.30
longitudinal extension of pile cap from column	f_{cu}(m)	variable	0.05	0.05	variable	0.0125	0.0125
transversal extension of pile cap from column	f_{cs}(m)	0.035	0.035	0.035	0.035	0.035	0.035
upstream extension of pile group to the pile cap	f_{pm}(m)	0.06	0.06	0.06	variable	0.06	0.06
pile cap thickness	T(m)	0.03	0.03	0.03	0.03	variable	variable
pile cap elevation from initial bed level	Y(m)	variable	-0.08	-0.08	-0.08	-0.08	variable
number of piles in line with flow	m	4	2	3	4	4	4
number of piles normal to the flow	n	2	2	2	2	2	2
pile diameter	b_p(m)	0.02	0.02	0.02	0.02	0.02	0.02
pile spacing long	S_m(m)	0.06	0.06	0.06	0.06	0.06	0.06
pile spacing width	S_n(m)	0.06	0.06	0.06	0.06	0.06	0.06

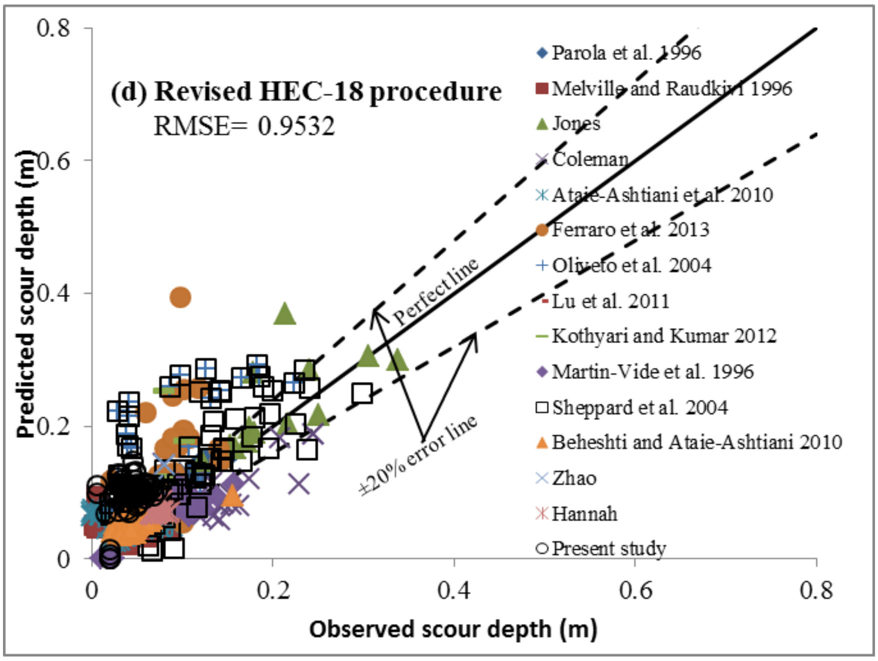
3. Predicting scour depth in complex piers

To evaluate the existing methods for the prediction of maximum scour depth in complex piers, the experimental data reported by Hannah (1978), Zhao, Martin-vide et al. (1996), Parola et al. (1996), Melville and Raudkivi (1996), Jones, Oliveto et al. (2004), Sheppard et al. (2004), Coleman (2005), Ataie-Ashtiani et al. (2010), Behshti and Ataie-Ashtiani et al. (2010), Lu et al. (2011), Kothyari and Kumar (2012), Ferraro et al. (2013), and the data presented in this study were considered. Consequently, the existing procedures [HEC-18 (Richardson and Davis 2001), Sheppard and Glasser (2004), Coleman (2005), Coleman (2005) Revised, and Hec-18 Revised] for scour depth prediction around complex piers were applied to the experimental data and their performance was evaluated. Fig. 2(a) shows results of the measured and predicted scour depths, y_s, using Coleman's (2005) procedure. In this figure, ±20% error lines and the line of perfect agreement are shown for comparison. This procedure was very conservative and estimated data had no well harmony with the observed data. In Fig. 2(b), all of the predicted scour depths, y_s, using the revised Coleman (2005) method have a better agreement with the observed data. It seems to be that revised Coleman (2005) procedure showed RMSE=0.9108 is as good as or better than Coleman (2005) procedure showed RMSE=0.8970. Fig. 2(c) is obtained using HEC-18 method (Richardson and Davis 2001), in which the estimated scour depths for the cases studied here are in fine accord with the observed values. Fig. 2(d) is obtained using the revised HEC-18 method (Ataie-Ashtiani et al. 2010). Results showed that the revised HEC-18 method exhibited significant improvement with respect to HEC-18 method. It could be seen that revised HEC-18 procedure showed RMSE=0.9532 is as good as or better than HEC-18 procedure showed RMSE=0.9438. In Fig. 2(e) a comparison between the observed and estimated scour depth is shown based on Sheppard et al.'s (2004) method. Using this procedure, only a few observed data had a good agreement with the estimated data based on the computed root mean square error, RMSE=0.9023. Overall, Coleman (2005) method and Sheppard et al.'s (2004) method uneconomically overestimated the maximum scour depths around the complex piers. Revised HEC-18 method performed better than HEC-18 method and the accuracy of the revised Coleman method and revised Hec-18 method was identical. These two methods performed better than others with more estimated values falling within ± 20 % boundaries.


(a) Coleman procedure
RMSE= 0.897
Predicted scour depth (m)
Observed scour depth (m)
Perfect Line
±20% error line
Parola et al. 1996
Melville and Raudkivi 1996
Jones
Coleman 2005
Ataie-Ashtiani et al. 2010
Ferraro et al. 2013
Oliveto et al. 2004
Lu et al. 2011
Kothyari and Kumar 2012
Martin-Vide et al. 1996
Sheppard et al. 2004
Behashti and Ataie-Ashtiani 2010
Zhao
Hannah
Present study


(b) Revised Coleman procedure
RMSE=0.9108
Predicted scour depth (m)
Observed scour depth (m)
Perfect line
±20% error line
Paro et al. 1996
Melville and Raudkivi 1996
Jones
Coleman
Ataie-Ashtiani et al. 2010
Ferrao et al. 2013
Oliveto et al. 2004
Lu et al. 2011
Kothyari and Kumar
Martin-Vide et al. 1996
Sheppard et al. 2004
Present study


(c) HEC-18 procedure
RMSE= 0.9438
Predicted scour depth (m)
Observed scour depth (m)
0
0.2
0.4
0.6
0.8
Perfect line
±20% error line
Parola et al. 1996
Melville and Raudkivi 1996
Jones
Coleman 2005
Ataie-Ashtiani et al. 2010
Ferraro et al. 2013
Oliveto et al. 2004
Lu et al. 2013
Kothyari and Kumar 2012
Martin-Vide et al. 1996
Sheppard et al. 2004
Beheshti and Ataie-Ashtiani 2010
Zhao
Hannah
Present study


(d) Revised HEC-18 procedure
RMSE= 0.9532
Predicted scour depth (m)
Observed scour depth (m)
0
0.2
0.4
0.6
0.8
Perfect line
±20% error line
Parola et al. 1996
Melville and Raudkivi 1996
Jones
Coleman
Ataie-Ashtiani et al. 2010
Ferraro et al. 2013
Oliveto et al. 2004
Lu et al. 2011
Kothyari and Kumar 2012
Martin-Vide et al. 1996
Sheppard et al. 2004
Beheshti and Ataie-Ashtiani 2010
Zhao
Hannah
Present study

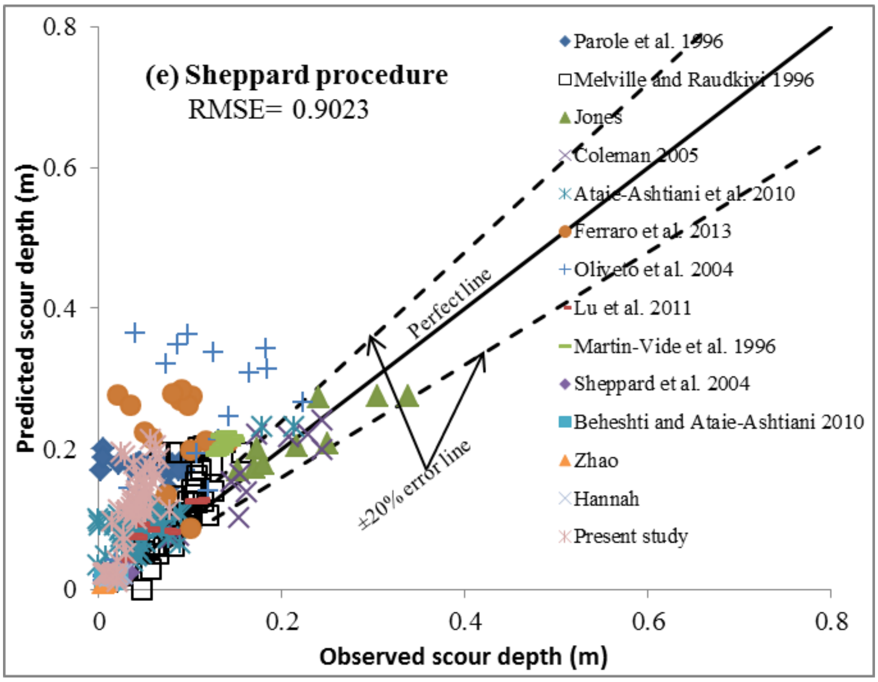


Figure 2. Comparison of the observed and predicted scour depths.

4. Conclusions

One of the problems may lead to bridge collapse is scouring. Many parameters may effect on bridge pier scour such as pier geometry, sediment, and flow characteristics. Here, the reported experimental data around complex bridge pier scour were collected. To evaluate the scour depth prediction, the existing methods were applied. Results showed that Sheppard et al. (2004) and Coleman (2005) methods were conservative. But, HEC-18, revised HEC-18, and revised Coleman (2005) predictions were more acceptable. The root square mean error, RSME was computed to evaluate recent procedures and it can be concluded that, Coleman (2005), Revised Coleman, HEC-18, Sheppard (2004), and Revised HEC-18 have a 0.897, 0.9108, 0.9438, 0.9532, and 0.9023 root mean square error (RSME), respectively.

5. References

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