Development of scour around a circular pier and its modelling using genetic algorithm

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ABSTRACT

This paper deals with generalized scour estimation to investigate maximum scour depth at equilibrium scour condition using experimental data obtained from experiments conducted by the authors along with data of previous researchers. Three hundred experimental data were used to derive the generalized clear water scour relationship around a circular bridge pier by using genetic algorithm (GA) and multiple linear regression (MLR) techniques. The GA-based maximum scour depth relationship showed more precise results than MLR. In addition, the present GA and MLR relationships were compared with some equations developed by earlier researchers. Graphically and statistically, it was observed that the GA and MLR relationships provide better agreement with experimental data as compared to earlier relationships. The present study highlights that the GA approach could be effectively used for estimation of maximum scour depth prediction around the bridge pier.

Key words | genetic algorithm, maximum scour depth and pier scour, multiple linear regression

HIGHLIGHTS

● Precise computation of maximum scour depth at bridge piers for the safe and economical design of the bridges.
● This study deals with generalized scour estimation to investigate maximum scour depth at equilibrium scour condition using experimental data.
● Three hundred experimental data were used to derive the generalized clear water scour relationship around a circular bridge pier by using GA and MLR techniques.
● Graphically and statistically, it was observed that the GA and MLR relationships provide better agreement with experimental data as compared to earlier relationships.
● We highlight that the GA approach could be effectively used for estimation of maximum scour depth predictions.

INTRODUCTION

In the present age of rapid industrialisation, a large number of bridges have been constructed to facilitate rapid movement of goods and people safely across the rivers. However, failure of bridges creates a disaster leading to immense loss of life and property. One of the key factors of alarm in stability of the bridge piers established in channel beds is the scour near the pier or other structure caused by the flowing water in the channels.

Piers form the sub-structure of bridges and support the super structure. Scour, defined as removal of sediment material from streams in the presence of any obstruction, has been accepted as a major reason of failure of bridge...
piers and other hydraulic structures (Pandey et al. 2016; Qi et al. 2016; Choufu et al. 2017; Pandey et al. 2019; Singh et al. 2019; Azizipour et al. 2020; Bestawy et al. 2020; Ghaderi et al. 2020; Pandey et al. 2020; Singh et al. 2020). Although scour around bridge piers have been studied quite extensively, scour-based failures still happen, which may be credited to an absence of information with respect to the processes of scour, updated design measures and an absence of widely existing outcomes from such studies (Kothyari & Ranga Raju 2001; Lança et al. 2015; Pu et al. 2014; Pandey et al. 2017, 2018, 2020). The development of scour near the piers is a highly complex process as it includes both the sediment transport phenomenon and the three dimensional characteristic of flow. Initially, the water flowing around the pier undergoes a three-dimensional separation, and then a separated shear layer rolls up along the pier and forms a vortex system at upstream phase of pier that moves downstream along the flow. Top view of this vortex system looks like a horseshoe shape; therefore, it is also known as a horseshoe vortex. The development of the horseshoe-vortex and the associated downflow near the pier results in increased shear-stresses and hence an increment in sediment transport process. This leads to the evolution of a scour hole near the pier which, in turn, causes variations in flow pattern resulting in a decrease in shear-stresses on the flowing water and decrease in sediment transport processes. The determination of scour around a pier continues to be the main concern for the hydraulic engineers.

In 1967–68, the main portion of the bridge nearby Belgaon in Orissa, India, was damaged by excess of scour (Pandey et al. 2018). Later, a different bridge was built at almost 400 m downstream, four piers of which were destroyed by another incomparable flood in 1977–78 (Kothyari 1989). Lately, Chadoora Bridge in Budgam, India failed due to scour in a 2014–15 flood event (Pandey et al. 2020). A report by the Federal Highway Administration claimed that more than 350 bridges failed due to disastrous floods in the year 1977. They reported that 25% of the bridges were destroyed due to scour around pier, whereas 75% were destroyed due to scour around abutment. In 1985–86, 73 bridges were affected due to flood in Pennsylvania, Virginia and West Virginia. In addition, 17 bridges failed in New England and New York due to scour near the bridge elements after a spring flood of 1987–88, as reported by the US Department of Transportation. All these studies on failure of bridges point towards the necessity of forecasting the scour near bridge elements accurately. Scour around a bridge pier in alluvial streams is still a substance of alarm, while there has been important advances made in this research area. Improving the understanding of the scour phenomenon is, therefore, vital in the design of foundations of hydraulic structure.

In the past, numerous researchers have proposed conservative, empirical, semi-empirical and analytical relationships based on scour mechanics, data correlation and dimensionless analysis of experimental data; worth mentioning among them are the contribution of Kothyari et al. (1992), Melville & Coleman (2000), Kothyari & Ranga Raju (2001), Sheppard et al. (2004), Lee & Sturm (2009), Lança et al. (2015) and Pandey et al. (2017, 2018).

Researchers have also attempted machine learning approaches to estimate scour around bridge piers. Azamathulla et al. (2009) successfully utilized linear genetic programming for predicting scour depth around circular piles, while Muzzammil (2010) and Muzzammil & Alam (2011) found an adaptive network-based fuzzy inference system (ANFIS) approach to be appropriate for predicting scour depths near bridge elements. Azamathulla et al. (2009) proposed a genetic algorithm relationship to predict maximum scour depth near a bridge pier and got realistic results compared to other approaches. In fact, previous studies show that the artificial intelligence has a wide application in the field of fluvial hydraulics and its associated subdivisions (Azamathulla et al. 2009; Pandey et al. 2020). Other studies in data-driven modeling include that of Lee & Sturm (2009), Azamathulla (2012), Lança et al. (2013), Link et al. (2017), Pandey et al. (2020), Ghodsi & Beheshti (2018).

Identifying the importance of pier scour, investigators have already proposed numerous empirical equations in past 20 years based on conventional data-driven modeling viz. regression method. The development of pier scour estimation methods is subjected to two main factors: (a) availability of data (collected data from field and laboratory experiments), (b) availability and application of efficient and effective modeling tools which may be applied to available data to develop specific pier scour estimation methods. Pandey et al. (2018) checked different maximum scour
depth relationships using field and laboratory pier scour data. The major difficulty with scour expressions is that such relationships are generally based on data that does not comprise all the parameters that contribute to the pier scour progression. Further, calibration of pier scour relationships with field experimental data is limited due to the lack of availability of appropriate accuracy and dimensions of the available data (Kothyari & Garde 2007). Therefore, there is a need that the modeling approaches applied to develop an empirical relationship for pier scour are more effective and might disclose the cause-and-effect relationship of the input and output variables involved in the entire process.

The objective of the present study is twofold: one is to propose maximum pier scour depth model in equilibrium stage using genetic algorithm (GA), and the other to compare the developed expression with well-known pier scour estimators. The present study is conducted for estimation of maximum scour depth at equilibrium stage under clear water scour condition only. Authors have compared the present scour expression with previously proposed relationships by Kothyari et al. (1992), Lee & Sturm (2009), Lança et al. (2013) and Pandey et al. (2020). It was observed by authors that each relationship showed acceptable outcomes only for a specific data range, based on pier geometry, hydraulic and sediment properties. In the present study, authors have used approximately 500 clear water maximum pier scour data for developing GA and MLR based maximum pier scour depth relationships. Out of total data, 70% data were used for training and the remaining 30% data were used for authentication of these equations.

OVERVIEW OF GA

GA, which is based on genetic programming (GP) (Azamathulla 2012) is an exploration method that includes mathematical algorithms. These algorithms are programmed in linear chromosomes that have frequently progressed to resolve a specific problem. GP is a complete arrangement, where phenotype and genotype are assorted together in a simple replicator scheme. Primarily, the chromosomes of each specific to the population are produced arbitrarily. Then, the chromosomes are expressed, and each specific one is assessed based on a fitness function and selected to reproduce with adjustment, leaving progeny with new individualities. This process is repeated for the predefined number of generations or until a solution is attained. Figure 1 defines GA through a simple flowchart. Application of optimization technique requires several steps before its execution as shown in Figure 1.

DATA COLLECTION AND DESCRIPTION

Clear-water pier scour data from flume experiments are taken from the previous studies (Kothyari 1989; Yanmaz & Altinbilek 1991; Dey et al. 1995; Sheppard et al. 2004; Raikar & Dey 2005; Das et al. 2013; Lança et al. 2013; Lodhi et al. 2014). Approximately 270 maximum scour depth data from previous studies were used in this study and, in addition, 12 clear-scour flume experiments have been conducted for non-cohesive uniform sediment. Compiling together around 280 clear-water scour data were used to check the performances of previous relationships as well as to propose new GA and MLR based relationships. Table 1 shows the sediment properties and hydraulic parameters where \(d_{50}\) is median diameter of sediment, \(b\) is pier diameter, \(U\) is approach mean velocity, \(y\) is depth of flow, \(B\) is channel width and \(U_c\) is critical velocity of sediment.

![Figure 1](http://iwaponline.com/ws/article-pdf/20/8/3358/813864/ws020083358.pdf)
EXPERIMENTAL SETUP AND PROCEDURE

The experiments were conducted in the Civil Engineering Department (hydraulic laboratory) of the Indian Institute of Technology, Roorkee, India. A 20 m long and 1.0 m wide tilting rectangular flume was selected for all the tests. The working section of this flume was 8 m long, 1.0 m wide and 0.38 m deep and starts 7 m from the flume entrance. The working section was completely filled with uniform gravel having 4.74 mm median diameter ($d_{50}$) and 1.38 standard geometric ($S$) deviation of particle size distribution with a constant value of specific gravity ($G$) of 2.65. The sediment in the working section was leveled with the help of a 2-D profiler with respect to rigid flume bed level. Four different hollow iron cylinders with diameters 6.6, 8.4, 11.5 and 13.5 cm were used as pier model. Supply of water in the flume was controlled by a valve, which was fixed in the inlet-pipe. The discharge in the flume was measured by the ultrasonic meter and the maximum scour depth was measured with point gauge at equilibrium scour stage. All the experiments were conducted for 24 h. But the condition of equilibrium scour stage was reached within 12–14 h. After equilibrium status, scour depth was similar over the time.

Prior to start of experimental run, piers were fixed perpendicular in the centre of working section and the sediment was properly leveled with respect to the longitudinal slope of the flume. After that the working section was covered with a 3 mm Perspex sheet and the predetermined hydraulic conditions were fixed with the help of an inlet valve and tail gate. When the predetermined conditions were met, the Perspex sheet was removed gradually so that there is no scour due to this process. Table 2 shows the present experimental limits with maximum equilibrium scour depth ($d_{se}$) at the upstream nose of the pier. Figure 2 illustrates the scour 1D depth profiles along the upstream and downstream nose of the pier. Figure 2 clearly illustrates that the maximum scour depth always occurs at the upstream nose of the pier; similar observations were found

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Range of present and previous experimental data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investigators</td>
<td>$d_{50}$ (mm)</td>
</tr>
<tr>
<td>Present study</td>
<td>4.78</td>
</tr>
<tr>
<td>Pandey et al. (2018)</td>
<td>0.4–11.3</td>
</tr>
<tr>
<td>Lodhi et al. (2014)</td>
<td>1.47–2.7</td>
</tr>
<tr>
<td>Lança et al. (2015)</td>
<td>0.22–2.9</td>
</tr>
<tr>
<td>Das et al. (2015)</td>
<td>0.825</td>
</tr>
<tr>
<td>Raikar &amp; Dey (2005)</td>
<td>4.1–14.25</td>
</tr>
<tr>
<td>Sheppard et al. (2004)</td>
<td>0.86</td>
</tr>
<tr>
<td>Dey et al. (1995)</td>
<td>0.26–0.58</td>
</tr>
<tr>
<td>Yanmaz &amp; Altinbilek (1991)</td>
<td>0.84–1.04</td>
</tr>
<tr>
<td>Kothyari (1989)</td>
<td>0.24–7.8</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Experimental condition and maximum scour depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exp. run</td>
<td>$b$ (cm)</td>
</tr>
<tr>
<td>T1</td>
<td>13.5</td>
</tr>
<tr>
<td>T2</td>
<td>13.5</td>
</tr>
<tr>
<td>T3</td>
<td>13.5</td>
</tr>
<tr>
<td>T4</td>
<td>11.5</td>
</tr>
<tr>
<td>T5</td>
<td>11.5</td>
</tr>
<tr>
<td>T6</td>
<td>11.5</td>
</tr>
<tr>
<td>T7</td>
<td>8.4</td>
</tr>
<tr>
<td>T8</td>
<td>8.4</td>
</tr>
<tr>
<td>T9</td>
<td>8.4</td>
</tr>
<tr>
<td>T10</td>
<td>6.6</td>
</tr>
<tr>
<td>T11</td>
<td>6.6</td>
</tr>
<tr>
<td>T12</td>
<td>6.6</td>
</tr>
</tbody>
</table>
by Melville & Coleman (2000). Scour depth at the upstream nose of the pier and maximum deposited dune height at the downstream side were at the maximum for the larger diameter of pier and higher values of velocity, as can be seen in Figure 2.

**METHODOLOGY**

Scour depth around bridge piers could easily be modelled using the soft computing approach. Performing the dimensional analysis relation between scour depth and other dependent variables, the relation may be expressed as

$$\frac{d_{se}}{y} = A(F_{d50})^B \left(\frac{y}{b}\right)^C \left(\frac{b}{d_{50}}\right)^D$$  \hspace{1cm} (1)

where, $d_{se}$ is the maximum scour, $y$ is depth of flow, $b$ is pier diameter, $d_{50}$ is median diameter of particles and $A$, $B$, $C$, $D$ are assumed as decision variables.

Experimental scour data composed by previous researches along with the experimental data obtained from the present laboratory set up was used to model scour depth estimates. Minimization of the sum of square of error between the observed and estimated scour depth is presented in Equation (2).

$$\text{Min } \text{SSE} = \sum_{i=1}^{N} \left[ \frac{d_{se}^{\text{observed}}}{y_i} - A(F_{d50})^B \left(\frac{y_i}{b_i}\right)^C \left(\frac{b_i}{d_{50}}\right)^D \right]^2$$  \hspace{1cm} (2)

where, $F_{d50} = \frac{U}{\sqrt{(S-1)gd_{50}}}$ densimetric Froude number, $S$ is relative density, $g$ is gravitational acceleration and $d_{50}$ is the median diameter of particles.

A, B, C and D are identified as the decision variables, however, in the present optimization model no constraints were required. The optimization model was formulated with the above-mentioned objective function and decision variables. Seventy percent of the data was used to calibrate the scour model and the rest of the data was used for validating the results. GA was selected as an optimization technique to model the scour depth adhering to its successful application in the field of water resource engineering (Pandey et al. 2020). Since GA is a population-based search technique, developed by Holland (1975), it has fewer chances of getting trapped in local optima. Unlike traditional gradient-based optimization techniques, search in GA is initialized through a set of points (population) rather than a single approximation as is the case of gradient-based techniques (Goldberg 1989). GA commences the exploration of optimal solution with random population of solutions that advances based on operators of genetic alteration and selection like inheritance, mutation, selection and crossover to obtain better child (chromosome) population (Pandey et al. 2020). Trapping into a local optimum solution is checked through mutation which ensures population diversity.

MATLAB programming language was used to model the scour relationship and obtain the optimal parameters.
through GA. MATLAB facilitates the use of GA through graphical user interface (GUI). GUI was adopted to designate the parameters like mutation rate, population size and convergence, etc. Population size in the range of 5–10 times the number of decision variables provides convergence in optimal time (Ghimire & Reddy 2010). In the present study, to model the scour equation, uniform creation function with a population size of 50 and the rank scaling function was adopted, while the mutation function was fixed as adaptive feasible (Zakwan et al. 2017; Pandey et al. 2020).

Multiple linear regressions (MLR) are another tool, which can be used to model the functions with more than one independent variable. Logarithmic transformation of Equation (1) yields the linear relationship as presented in Equation (3).

\[
\log\left(\frac{d_{sc}}{y}\right) = \log A + B \log(F_{d50}) + C \log\left(\frac{y}{b}\right) + D \log\left(\frac{b}{d_{50}}\right) \tag{3}
\]

Using Equation (3), scour depth may be estimated based on MLR approach with a simple data analysis add-in available in Microsoft Excel. The data analysis add-in provides a user-friendly window to select cells associated with dependent and independent variables. Once the selection has been made, an inbuilt program runs to provide the coefficients of various independent variables.

**RESULTS AND DISCUSSION**

The parameters of Equation (3) attained after application of MLR and GA approaches are presented in Table 3. The difference in parameters attained may be due to the fact that the parameters attained from the MLR approach are those obtained from fitting of log transformed data instead of actual data.

<table>
<thead>
<tr>
<th>Table 3</th>
<th>Coefficients obtained by GA and MLR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Method</td>
<td>A</td>
</tr>
<tr>
<td>MLR</td>
<td>1.410</td>
</tr>
<tr>
<td>GA</td>
<td>1.064</td>
</tr>
</tbody>
</table>

**VALIDATION OF PREVIOUS RELATIONSHIPS**

In the present study, four dimensionless maximum scour equations given by Kothyari et al. (1992), Lee & Sturm (2009), Lança et al. (2013), and Pandey et al. (2018) were used for comparative analysis. Data collected from the present and previous studies were used for checking the performances of these relationships, graphically and statistically. Figure 3 shows the percentage error of observed and measured dimensionless scour depths while using these equations.

Kothyari et al. (1992) proposed a semi-analytical method to predict the maximum scour depth near the bridge pier and suggested that primary vortex system is the main factor governing the scour processes. On the basis of principles of sediment transport and their wide experimental data, they suggested a method for calculating the maximum scour depth, given by Equation (4).

\[
\frac{d_{sc}}{b} = 0.88 \left(\frac{b}{d_{50}}\right)^{0.67} \left(\frac{y}{d_{50}}\right)^{0.4} (\beta^{-0.3}) \tag{4}
\]

where, \(\beta = (B - b)/B\).

The calculated values of dimensionless maximum scour depth using Kothyari et al. (1992) approach have been plotted against observed dimensionless maximum scour depth, illustrated in Figure 3(a). Fine sediment data sets for \(U/U_c < 0.7\) appear to be in agreement with the observed data. Hence, it can be concluded that Equation (4) calculates maximum scour depth well only for fine sediment bed and \(U/U_c < 0.7\).

Lee & Sturm (2009) collected data from literature (Ting et al. 2001; Sheppard et al. 2004) as well as from their own experiments and used this data to get correction factors recommended by Melville & Coleman (2000) in order to separate the influence of \(b/d_{50}\). A final two relationships were proposed by them as given by Equations (5a) and (5b) that have been used here.

\[
\frac{d_{sc}}{b} = 5.0 \log \frac{b}{d_{50}} - 4.0 \quad 6 \leq \frac{b}{d_{50}} \leq 25 \tag{5a}
\]

\[
\frac{d_{sc}}{b} = \frac{1.8}{\left(\frac{0.02b - 0.2}{d_{50}}\right)^2} + 1.3 \quad 25 \leq \frac{b}{d_{50}} \leq 10^4 \tag{5b}
\]
Figure 3 | Observed and calculated maximum dimensionless scour depths as per (a) Kothyari et al. (1992), (b) Lee & Sturm (2009), (c) Lanca et al. (2013), (d) Pandey et al. (2018), (e) GA approach, and (f) MLR approach.
The calculated values of dimensionless maximum scour depth using Lee & Sturm (2009) approach has been illustrated in Figure 3(b). Data sets of smaller values of $b/d_{50}$ (<25) with coarser sediment show good agreements between observed values of dimensionless scour depth. Therefore, it can be concluded that Equation (5) calculates maximum scour depth well only for coarser sediment with small values of $b/d_{50}$ ratio.

Lança et al. (2013) conducted clear-water scour experiments for a long duration. They explored the influence of sediment size on the maximum scour depth and proposed improved scour evaluation equations given by Equations (6a) and (6b).

$$d_{se} = 7.3 \left( \frac{b}{d_{50}} \right)^{-0.29} \left( \frac{y}{b} \right)^{0.12} \text{ for } 60 \leq \frac{b}{d_{50}} \leq 500$$  \hspace{0.5cm} (6a)

$$d_{se} = 1.2 \left( \frac{b}{d_{50}} \right)^{0.12} \text{ for } \frac{b}{d_{50}} > 500$$  \hspace{0.5cm} (6b)

It was observed by them that the effect of the flow shallowness is further evident for bigger pier width. They derived that maximum scour depth equation after examining pier scour data of large value of $b/d_{50}$ ratio. However, in the present study, authors used pier scour data with small as well as huge value of $b/d_{50}$ ratio. Therefore, only 50% of datasets appear to fit under the line of agreement and only those maximum scour depth data lie inside the line of agreement which have a large value of $b/d_{50}$, as shown in Figure 3(c).

Pandey et al. (2018) conducted clear-water scour experiments for pier scour and proposed a non-dimensional scour depth after checking the accuracy of previous maximum scour depth equations. They recognised densimetric particle Froude number ($F_{d_{50}}$) as the primary factor effecting maximum scour depth while the other variables show a lesser effect on maximum scour depth. Based on their analysis, Pandey et al. (2018) proposed a non-dimensional relationship given by Equation (7).

$$\frac{d_{se}}{y} = 0.987 F_{d_{50}}^{0.302} \left( \frac{b}{d_{50}} \right)^{-0.566} \left( \frac{b}{d_{50}} \right)^{0.079}$$  \hspace{0.5cm} (7)

Equation (7) has a good value of regression coefficient ($R^2 = 0.88$) for the data used in evolving this relationship. However, authors focused on gravel bed data for proposing this relationship. This equation showed good results only for gravel and coarse sand bed. This relationship doesn’t show appropriate results for fine sand bed as shown in Figure 3(d). The data sets from Kothyari (1989) and Sheppard et al. (2004) appear to diverge from the line of agreement than that of coarser bed data, while the gravel bed dataset are more supportive near the least error as shown in Figure 3(d). A sensitivity analysis was also done by Pandey et al. (2018) before finalizing the variables of Equation (7). The result of sensitivity analysis too reinforced the assumption that the $F_{d_{50}}$ is the most sensitive parameter, whereas the other parameters exercise lesser impact on scour depth (Pandey et al. 2018).

However, Figure 3(a)–3(f) demonstrates that the scour depth estimated by GA is most reliable as it results in least error and highest efficiency. Figure 4 shows the statistical values of present and previous relationships using maximum scour depth data. Large SE were observed for Kothyari et al. (1992) relationship, mostly because of limited experimental data used by them for proposing that relationship. Further, the application of logarithmic transformation in case of MLR leads to bias in the estimates (Miller 1984; Ferguson 1986; Zakwan et al. 2017; Pandey et al. 2020). Application
of GA approach has shown the most consistent estimation of maximum dimensionless scour depths.

The maximum estimated scour depth proposed by previous researchers was also statistically matched to those proposed by earlier investigators. Statistical relative investigation of calculated maximum scour depth was made on the basis of the following measures.

Root mean square (RMSE)
\[ \text{RMSE} = \sqrt{\frac{\sum_{i=1}^{n} (X_i - Y_i)^2}{N}} \]  
(8)

Standard Error (SE)
\[ \text{SE} = \sqrt{\frac{\sum_{i=1}^{n} (X_i - Y_i)^2}{N(N - 1)}} \]  
(9)

Nash coefficient (NC)
\[ \text{NC} = \left[ 1 - \frac{\sum_{i=1}^{n} (X_i - Y_i)^2}{\sum_{i=1}^{n} (X_i - \bar{X})^2} \right] \]  
(10)

Coefficient of correlation (CC)
\[ \text{CC} = \frac{\sum_{i=1}^{n} (X_i - \bar{X})(Y_i - \bar{Y})}{(N - 1)S_XS_Y} \]  
(11)

where, \( X_i \) is the observed depth of scour; \( Y_i \) is predicted depth of scour; \( N \) = number of observation; \( S_X \) and \( S_Y \) are standard deviation of \( X \) and \( Y \).

In Equations (8)–(11), the values of RMSE, SE, NC and CC of each equation are illustrated in Figure 4. The values of NC and CC of GA approach are highest, and the values of RMSE and SE are lowest as compared to other approaches. Statistically, we may conclude that the GA approach performs better than others, as can be seen in Figure 4. However, statistically, GA approach has an edge over present MLR approach and the relationship proposed by Pandey et al. (2018).

CONCLUSIONS

Estimation of maximum scour depth at equilibrium scour condition is important to protect the bridge piers throughout the flood events and helps to design a safe and realistic bridge foundation. The previous sections defined an application of the reasonably new soft-computing technique of GA to calculate the maximum scour depth at equilibrium scour condition around the circular bridge pier. Two relationships based on GA and MLR were derived to calculate the maximum scour depth around a circular pier.

Four earlier proposed maximum scour depth equations were analysed, statistically and graphically. Equations proposed by Pandey et al. (2018) and Lança et al. (2013) showed good results but only for a specific data range. It was observed that the prediction of maximum scour depth using GA was objectively precise and comparable with the earlier equations given by Pandey et al. (2018) and Lança et al. (2013). GA and MLR based equations were also analysed graphically and statistically; the resulting values of maximum scour depths using these equations showed more realistic results with experimental data as compared with previous equations. Between GA and MLR equations, the GA based equation estimated maximum scour depth more accurately.

ACKNOWLEDGEMENTS

The authors would like to thank the anonymous reviewers for their valuable comments which improved the quality of the paper. Thanks are also due to Professor Hazi Azamathulla, The University of the West Indies, Trinidad.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES


First received 8 July 2020; accepted in revised form 17 September 2020. Available online 1 October 2020