# Prediction of Pier and Pile Group Scour Due to Waves and Currents

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## 1- Database and existing methods

Table 1. List of data for pier and pile group scour due to waves and currents

| Ref. | Pile group (# of tests) | Pier (# of tests) | Wave | Current |
|---|---|---|---|---|
| Sumer and Fredsøe (1998) | 46 | – | Yes | – |
| Bayram and Larson (2000) | 58 | – | Yes | – |
| Sumer et al. (1992) | – | 53 | Yes | – |
| Dey et al. (2006) | – | 41 | Yes | – |
| Sumer et al. (2007) | – | 48 | Yes | – |
| 2012 Dongfang et al. | Not accessible | – | Yes | – |
| Sumer and Fredsøe (2001a) | – | 27 | Yes | Yes |
| Mostafa and Agamy (2011) | 24 | 8 | Yes | Yes |

Table 2. List of methods of pier scour prediction, including soft computing methods

| Reference | Formula / Explanation |
|---|---|
| Sumer et al. (1992) | Formula for: pier wave scour<br>Database: their own data<br>Method: regression<br>$y_s/b_p = 1.3\left(1-e^{-0.03(KC-6)}\right)$ |
| Ayoubloo et al. (2010) | Formula for: pier wave scour<br>Database: Sumer et al. (1992) & Dey et al. (2006) (88 data)<br>Method: NN; 75% training, 20% test; 1 hidden layer with 3 nodes<br>$\frac{y_s}{b_p} = f\left(\mathrm{Re}, \theta, KC, N_s\right)$ wherein $\mathrm{Re} = \frac{U_m b_p}{\nu}, \theta = \frac{U_{fm}^2}{g\left(SG-1\right)d_{50}}$<br>$, KC = \frac{U_m T}{b_p}, N_s = \frac{U_m}{\sqrt{g\left(SG-1\right)d_{50}}}, U_{fm} = \left(0.5f\right)^{1/2} U_m$ |
| Guven et al. (2009) | $y_s/b_p = f\left(q, KC, Ns, \mathrm{Re}, Dr\right)$<br>$KC = \frac{U_m T}{b_p}, \mathrm{Re} = \frac{U_m b_p}{\nu}, q = \frac{U_{fm}^2}{g\left(SG-1\right)d_{50}}, \mathrm{Re}_e = \frac{U_{fm} d_{50}}{\nu},$<br>$Ns = \frac{U_m}{\sqrt{g\left(SG-1\right)d_{50}}}, Dr = \frac{e_{\max}-e}{e_{\max}-e_{\min}}, U_{fm} = \left(0.5f\right)^{1/2} U_m$<br>database: Sumer et al. (2007) (38 data)<br>75% training, 25% for validation<br>- It gives a explicit formula using genetic programming (very long formula)<br>- ANFIS was also used for the dimensionless model<br>6 input variables, two membership functions each, that's $2^6$=64 functions each one has 7 coefficients, totally 448 coefficients, also 2 coefficients for each membership function = 2*6*2=24, totally 472 coefficients |

Table 3. List of methods of pile scour prediction, including soft computing methods

| | |
|---|---|
| Mostafa et al. (2011) | $\frac{y_{s(current+wave)}}{y_{s(current)}} = \begin{cases} 0.2 + 0.023 G/b_p & \text{for tandem} \\ 0.175 + 0.0307 G/b_p & \text{for side by side} \end{cases}$ |
| Etemad-Shahidi and Ghaemi (2011) | Formula for: pile group wave scour<br>Database: Sumer and Fredsøe (1998) & Bayram and Larson (2000) (108 data)<br>Method: Model tree<br>$y_s/b_p = \begin{cases} 0.05 n^{0.46} m^{-0.67} KC^{0.95} \left[1 - e^{-(G/b_p + 0.1)}\right]^{0.2} & \text{for } G/b_p \le 2.46 \\ 0.48 n^{0.14} m^{0.08} KC^{0.47} \left[1 - e^{-(G/b_p - 1)}\right]^{0.16} & \text{for } G/b_p > 2.46 \end{cases}$ |
| Bateni and Jeng (2007) | $\frac{y_s}{b_p} = f\left(N_{RE}, N_s, \theta, KC\right)$<br>$N_{RE} = \frac{U_m D}{\nu}, N_s = \frac{U_m}{\sqrt{g\left(SG-1\right)d_{50}}}, \theta = \frac{U_{fm}^2}{\left(SG-1\right)g d_{50}}, KC = \frac{U_m T}{D}$<br>Data: Bayram and Larson (2000) |
| Ghazanfari-Hashemi et al. (2011) | $\frac{y_s}{b_p} = f\left(\mathrm{Re}, Ns, \theta, KC, m, n, \frac{G}{b_p}\right)$<br>$\mathrm{Re} = \frac{U_m b_p}{\nu}, N_s = \frac{U_m}{\sqrt{g\left(SG-1\right)d_{50}}}, \theta = \frac{U_{fm}^2 b_p}{\left(SG-1\right)g d_{50}}, KC = \frac{U_m T}{b_p}$<br>Database: Sumer and Fredsøe (1998) & Bayram and Larson (2000)<br>methods: NN: 6-1-1 architecture was used,<br>SVM used too |

The variables used are $y_s$=scour depth, $b_p$=pier width, $KC$=Keleugan-Carpenter number defined as $KC=U_mT/b_p$, wherein $U_m$=orbital velocity at the bed and $T$ = wave period; $Fr_d$=densimetric Froude number defined as $Fr_d=V/[(SG\text{-}1)gd_{50}]$ wherein $V$ = current velocity, $SG$=specific gravity of the sediment = 2.65, $g$=9.81 m/s$^2$ and $d_{50}$=median bed sediment size. For pile group, $n$ = number of piles perpendicular to the flow, $m$ = number of piles inline with the flow and $G/b_p$=gap ratio are also used wherein $G$=open gap between the adjacent piers.

## 2. Developing new formulas

For single piers, a total of 210 data were used from the following sources: Sumer et al. (1992) with 49 data, Carreiras et al. (2001) with 25 data, Sumer and Fredsøe (2001a) with 25 data, Sumer and Fredsøe (2001b) with 16 data, Dey et al. (2006) with 41 data, Sumer et al. (2007) with 48 data, and Mostafa and Agamy (2011) with 6 data. The range of variables are: $0.3 \le KC \le 102$, $0 \le Fr_d \le 14.8$ and $0 \le y_s/b_p \le 1.67$. The existing studies that have performed regression or soft computing analysis on wave scour on piers include: Guven et al. (2009), Ayoubloo et al. (2010), Guven et al. (2009) and Webb and Matthews (2014). However, have either used a small database, or have used a large database but have not included the effect of current (represented by $Fr_d$ here) in addition to wave as some of the experiments they considered include currents too. The formula for the scour in this situation was developed using model trees which is expressed by

$$\frac{y_s}{b_p}=\begin{cases}1.36\left(\dfrac{KC}{12}+0.1\right)^{0.55-0.5\times KC/12}\left(\dfrac{Fr_d}{14}+0.1\right)^{0.96} & \text{for } KC\le 12\\ 2.32\left(\dfrac{KC}{30}\right)^{0.83-0.14\times KC/30}\left(\dfrac{Fr_d}{14}+0.1\right)^{0.53} & \text{for } KC>12\end{cases}$$

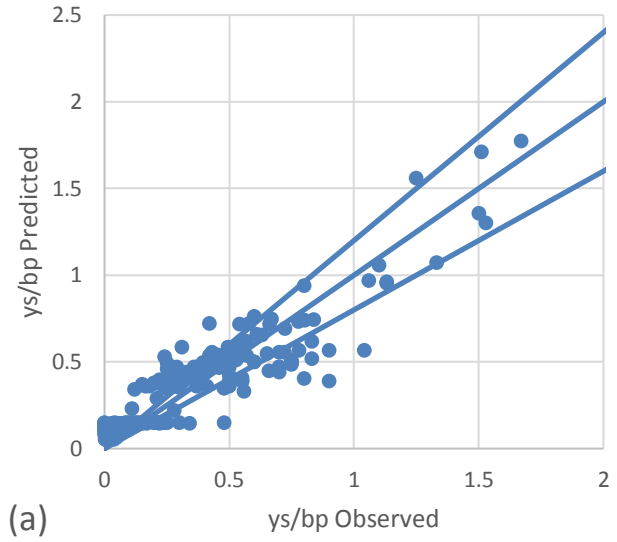


Fig. 1. Pier scour due to waves: prediction vs. Observation

For pile groups, a total of 126 data were used from the following sources: Sumer and Fredsøe (1998) with 44 data, Bayram and Larson (2000) with 58 data, and Mostafa and Agamy (2011) 24 data. The range of variables are: $3\le KC\le 37$, $1\le n\le 4$, $1\le m\le 4$, $0\le G/b_p\le 4$, $0\le Fr_d\le 2.78$ and $0.1\le y_s/b_p\le 3.5$. The existing studies that have performed regression or soft computing analysis on wave scour on pile groups include: Kambekar and Deo (2003), Bateni and Jeng (2007), Etemad-Shahidi and Ghaemi (2011) and Ghazanfari-Hashemi et al. (2011). These studies do not include the data related to the effect of wave and current. The formula for scour in pile groups due to wave and scour developed here is:

$$\frac{y_s}{b_p}=\begin{cases}2.43\left(\dfrac{KC}{12}+0.1\right)^{0.16}\left(\dfrac{Fr_d}{3}+0.1\right)^{-0.41}\left(\dfrac{G}{b_p}\right)^{0.2} m^{1.22}\mathrm{n}^{1.34} & \text{for } KC\le 12\\ 0.69\left(\dfrac{KC}{12}+0.1\right)^{0.93}\left(\dfrac{Fr_d}{3}+0.1\right)^{0.91}\left(\dfrac{G}{b_p}\right)^{0.73} m^{-0.39}n^{-0.097} & \text{for } KC>12\end{cases}$$

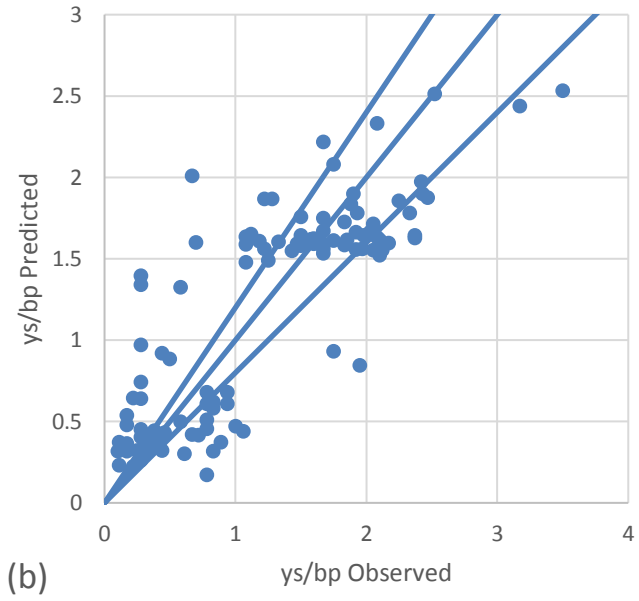


Fig. 2. Pier scour due to waves: prediction vs. Observation

**3. Data availability**

The database used in this study is available through Google Sheets. To access the data, follow this link (no Google login required):
https://docs.google.com/spreadsheets/d/1siXzBCpYahWHC01HN2_os0qiYUyjZE8hH0_JqmCG3hw/edit?usp=sharing

In order to be able to make edits, select "Make a copy" from File menu. Making a copy requires an active Google account. The functions are written in Google Script code, which is similar to Java script, and can be accessed from "Script editor" in the Tools menu. Java script codes are also available in the following link:
https://github.com/DanialAmini/Pier-PileGroup-Wave-Scour

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