Implementation of Bridge Pilings in the ADCIRC Hydrodynamic Model: Upgrade and Documentation for ADCIRC Version 34.19

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INTRODUCTION

Given the typical resolution of coastal circulation models, (e.g., in nearshore applications resolved scales are usually 10s to 100s of meters and larger), it is rarely practical to solve explicitly for the small scale flow around obstructions such as bridge pilings (diameters of meters). However, in some situations it may be desirable to include the effects of these subgrid scale obstructions on the resolved scale flow. To accomplish this, a subgrid scale obstruction parameterization has been developed and implemented in ADCIRC. Since the cross-sectional area of these obstructions is usually quite small compared to the cross-sectional area of the flow field (and thus the effect on flow continuity is quite small), their primary effect is to impart additional drag on the resolved scale flow. This report describes the theory behind the obstruction parameterization implemented in ADCIRC, the procedure for utilizing it in a model run and the performance on a simple test case.

THEORY

The two-dimensional, vertically integrated momentum equations used in ADCIRC (e.g., Eqs. 25 and 26 in Luettich et al. 1992) contain bottom friction (drag) terms, τ_{bx}, τ_{by} as shown below:

$$\frac{\partial U}{\partial t} + U\frac{\partial U}{\partial x} + V\frac{\partial U}{\partial x} - fV = -\frac{\partial}{\partial x}\left[\frac{p_s}{\rho_o} + g\left(\zeta - \alpha\eta\right)\right] + \frac{1}{H}\left[M_x + D_x + B_x + \frac{\tau_{sx}}{\rho_o} - \frac{\tau_{bx}}{\rho_o}\right]$$

$$\frac{\partial V}{\partial t} + U\frac{\partial V}{\partial x} + V\frac{\partial V}{\partial x} + fU = -\frac{\partial}{\partial y}\left[\frac{p_s}{\rho_o} + g\left(\zeta - \alpha\eta\right)\right] + \frac{1}{H}\left[M_y + D_y + B_y + \frac{\tau_{sy}}{\rho_o} - \frac{\tau_{by}}{\rho_o}\right]$$

To represent the extra drag caused by subgrid scale obstructions such as bridge pilings, a second contribution has been added to τ_{bx}, τ_{by}, i.e.,

$$\frac{\tau_{bx}}{\rho_o} = \textit{bottom friction } x + \textit{obstruction drag } x \quad \text{and} \quad \frac{\tau_{by}}{\rho_o} = \textit{bottom friction } y + \textit{obstruction drag } y$$

Options in ADCIRC exist to express the *bottom friction* terms as linear, quadratic or hybrid quadratic/manning's n functions of flow velocity (Luettich and Westerink, 1999). The *obstruction drag* is assumed to be due primarily to form drag and therefore is represented as quadratic in velocity:

$$\textit{obstruction drag } x = C_p U\left|U^2 + V^2\right| \quad \text{and} \quad \textit{obstruction drag } y = C_p V\left|U^2 + V^2\right|$$

where C_p is an obstruction (piling) drag coefficient.

To determine C_p for a series of bridge pilings, we have utilized the extensive body of research conducted in the early to mid 1900s on flow around pilings. Yarnell (1934a,b), as summarized by Henderson (1966), fit the change in water level $\Delta\zeta$ for steady, unidirectional flow past a piling to the following relation:

$$\frac{\Delta\zeta}{H} = -K\,Fr^2\left(K + 5Fr^2 - 0.6\right)\left(\alpha + 15\alpha^4\right)$$

where, H is the total water depth, K is a pier shape factor (Table 1), $Fr^2 = U_s^2/gH$ is the square of the Froud number, α is the fraction of the cross section obstructed by the piling, U_s is the velocity in the along stream (s) direction and g is the acceleration of gravity. This equation is considered to be valid so long as $\alpha < 0.5$.

Table 1. recommended pier shape factors

Pier Shape	*K*
Semicircular nose and tail	0.9
Lens-shaped nose and tail	0.9
Twin-cylinder piers with connecting diaphragm	0.95
Twin-cylinder piers without diaphragm	1.05
90 deg triangular nose and tail	1.05
Square nose and tail	1.25

For this same case of steady, unidirectional flow in the vicinity of pilings, the corresponding ADCIRC momentum equations simplify to:

$$\frac{\partial\zeta}{\partial s} = -C_p Fr^2$$

where $\partial\zeta/\partial s$ is the free surface gradient in the along stream direction. Approximating this gradient as $\Delta\zeta/\Delta s$, Yarnell's equation and the simplified momentum equation can be combined to obtain an expression for C_p:

$$C_p = \frac{HK\left(K + 5Fr^2 - 0.6\right)\left(\alpha + 15\alpha^4\right)}{\Delta s}$$

This equation is used at each time step in ADCIRC, to compute C_p at all nodes associated with bridge pilings. This allows the obstruction drag to be computed and added to the bottom friction terms as discussed above.

We note that Yarnell's equation is based on H and U_s values measured at a point downstream of the pilings. ADCIRC uses H and U_s at the effective piling location to minimize complications due to changing flow direction, e.g., due to reversal of the tide. Typical elevation and velocity changes that result are small enough that the overall results are not compromised by this approximation.

USING THE BRIDGE PILING OPTION IN ADCIRC VERSION 34.19

Special considerations must be used when designing a grid for an ADCIRC application that includes the effects of bridge pilings. Specifically, it is necessary to build the grid to provide at least three rows of nodes that parallel the bridge span. One row of nodes (centerline nodes) should lie along the approximate centerline of the bridge while the second and third rows of nodes (adjacent nodes) should lie on either side of the centerline nodes in the along steam direction. An initial implementation of obstruction drag in ADCIRC placed this drag entirely at the row of centerline nodes. However, tests showed that this arrangement led to significant oscillations in the numerical solution. The oscillations abated when the obstruction drag was distributed in the along stream direction so that 25 percent was located at each row of adjacent nodes and 50 percent was located at the row of centerline nodes. Node numbers and coefficient values at *all* nodes on the centerline and two adjacent rows must be entered in the ***fort.21*** file (as described below). It is not necessary for centerline nodes to correspond to actual piling positions, (i.e., in the cross stream direction), since the overall effect of the pilings on the large scale circulation is all that is being represented. It is important, however, to construct a grid that is as uniform as possible in the vicinity of the bridge.

The presence of bridge pilings is signaled to ADCIRC via the parameter NWP located in the master input parameter file (***fort.15***). Depending on the value specified for NWP, ADCIRC may read in spatially varying frictional information from a ***fort.21*** file. The parameter NWP may have the following values:

NWP = 0	Spatially constant linear or nonlinear bottom friction. Friction parameters are read from the ***fort.15*** file.
NWP = 1	Spatially varying linear or quadratic bottom friction. Requires reading in spatially varying friction coefficients for the entire grid from the ***fort.21*** file. This option does not work for NOLIBF=2.
NWP = 2	Localized areas of enhanced friction due to bridge pilings. Requires reading node numbers and appropriate coefficients from the ***fort.21*** file.

FORMAT OF THE SPATIALLY VARYING FRICTION COEFFICIENT/BRIDGE PILING COEFFICIENT FILE

The format for the ***fort.21*** file depends on the value specified for NWP as follows:

NWP = 0 the ***fort.21*** file is not read

NWP = 1 the ***fort.21*** file has the following format:

AFRIC
I, FRIC(I) (this line is repeated for I=1,NP)

where,

AFRIC = alphanumeric file identifier (only the 1st 24 characters are read)
I = node number in the ADCIRC grid
FRIC(I) = linear or quadratic friction coefficient for node I
NP = number of nodes in the ADCIRC grid

NWP = 2 the ***fort.21*** file has the following format:

AFRIC
NBPNODES
NBNNUM(I),BK(I),BALPHA(I),BDELX(I),POAN(I) (this line is repeated for I=1,NBPNODES)

where,

AFRIC = alphanumeric file identifier (only the 1st 24 characters are read)
NBPNODES = total number of nodes (centerline and adjacent) in ADCIRC grid used to represent the effects of bridge pilings
NBNNUM(I) = node number in ADCIRC grid of node I used to represent the effects of bridge pilings
BK(I) = pier shape factor (*K* - see Table 1)
BALPHA(I) = fraction of the cross section occupied by all of the pilings in the bridge = sum of piling widths/width of cross section (corresponds to α in theory section above)
BDELX(I) = approximate nodal spacing in the upstream/downstream direction in meters or feet depending on the grid coordinate system (for lon,lat coordinates, use meters for BDELX). (Note that $\Delta s \approx 2$*BDELX if the piling effects are distributed across 3 nodes in the alongstream direction)
POAN(I) = parameter that weights drag between adjacent and centerline nodes.
  = 2 if node represents a centerline node
  = 1 if node represents an adjacent node

TEST CASE

The implementation of the bridge piling algorithm has been tested in ADCIRC V34.19 using a simple rectangular channel of length 12 *km*, width 2 *km* and depth 10 *m*. The channel was discretized using a uniform node placement with $\Delta x = \Delta y = 250$ *m* yielding a grid with 49 nodes along the length and 9 nodes across the width. Flow along the length of the channel was driven by a steady inflow at one end and steady outflow at the other end with a discharge per unit width of 10 m^2/s. The nominal velocity in the channel (discharge/depth) equals 1 *m/s*.

An approximate solution to the water level change along the length of the channel in the absence of any bridge pilings (and neglecting the Coriolis force) can be obtained by a simple balance between the water level slope and the bottom friction:

$$\frac{\partial \zeta}{\partial x} = -\frac{C_d U^2}{gh} = -\frac{(0.0025)(1^2)}{(9.81)(10)} = -2.548x10^{-5}$$

This yields a linear water surface slope along the length of the channel with a total water level drop over 12 *km* of 0.3058 *m*.

Figure 1 presents the steady state water level profile along the channel centerline computed by ADCIRC. The total water level drop over 12 *km* is 0.3091 *m*.

A second test case was then performed in which a bridge was assumed to cross the channel 6.5 *km* from the upstream end. Nine nodes were specified as centerline nodes and 18 nodes were specified as adjacent nodes. At each of these 27 nodes, BK=1.0, BALPHA=0.1 and

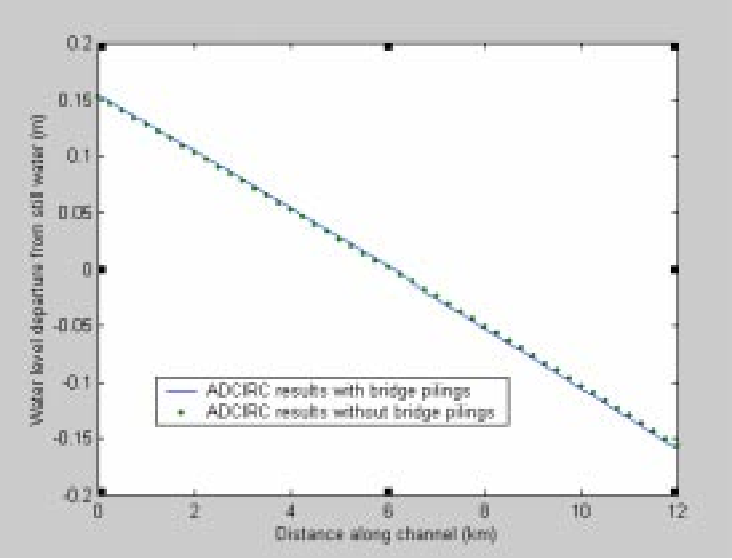

Figure 1. Along channel water level profile computed by ADCIRC with and without bridge pilings. Results have been plotted at every grid point along the length of the channel.

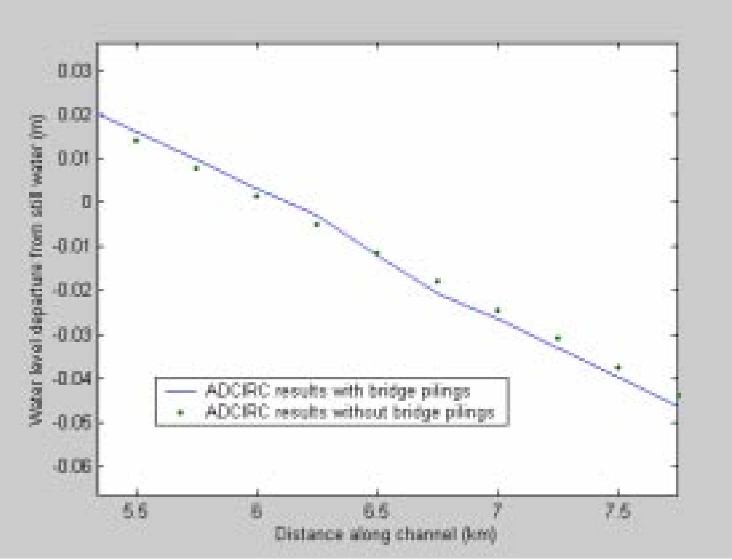

Figure 2. Blow up of the along channel water level profile computed by ADCIRC with and without bridge pilings. Results have been plotted at every grid point in the vicinity of the bridge.

BDELX=250, corresponding to a bridge with a piling shape factor of 1, the total area of pilings equal to 10 percent of the channel cross sectional width and a grid spacing of 250 *m*. Using Yarnell's equation ($Fr^2 = 1^2/(9.81)(10) = 0.1019$, K=1, α =0.1) gives a water level drop across the pilings of $\Delta\zeta$ =0.00467 *m*.

Figures 1 and 2 present the steady state water level profile along the channel centerline computed by ADCIRC. It is clear that the water level drop is increased due to the presence of the bridge pilings. The total water level drop along the channel in this run is 0.3133 *m* indicating that the pilings caused a water level drop in the ADCIRC run of 0.3133 – 0.3091 = 0.0042 *m*. This value is approximately 10 percent below the Yarnell value. Near perfect agreement can be obtained by "calibrating" the numerical method by reducing BDELX to 90 percent of the nodal spacing (225 *m*). It is not know, however, whether this can be generalized to all applications.

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