CHAPTER 5

ANALYSIS OF THE BUBBLE SCREEN
FLOW FIELD IN FLOWING WATER

5.1 The Problem

In order to describe the bubble screen shape in flowing water, it is necessary to know the vertical and horizontal velocities of the bubbles at every instant.

This task is complicated because the size of the bubbles is not constant, not in horizontal plane and not in vertical plane (the bubbles expand when they rise). Another problem is the mutual action between the bubbles when they rise close to each other.

In this chapter, an approximation for the bubble screen shape in flowing water is made.

5.2 Analysis of the Bubble Screen Shape in Flowing Water

The air bubbles move faster than the local fluid velocity by an amount referred to as slip velocity, $U_s$. There are strong indications for the constancy of $U_s$ in both stagnant and moving liquids. The vertical water velocity at the centerline of the bubble screen is also constant for a given air discharge. These results lead to a conclusion that the bubbles rising velocity should be closed to constant. The average rising velocity of the bubbles was given by Helmut Kobus as a result of experiments:
\[ \overline{v}_b = \sqrt{g H_o} \cdot 0.48 \cdot \left( \frac{Q_o}{\sqrt{g H_o}} \right)^{1/6} \]  

(5.1)

Basing on this equation it is possible to write:

\[ y_b(t) = \overline{v}_b \cdot t \]  

(5.2)

In which \( y_b \) is measured from the bed.

The horizontal velocity profile in the rough turbulent range is:

\[ u = u_f \cdot 2.5 \ln \frac{29.7 \overline{v}_b}{k} \]  

(5.3)

where

\[ u_f = \sqrt{\frac{\tau_o}{\rho_w}} \]  

(5.4)

using equation (5.2), the following can be obtained:

\[ x_b(t) = \int_0^t u_f \cdot 2.5 \ln 29.7 \frac{\overline{v}_b \cdot t}{k} \, dt \]

\[ = \int_0^t u_f \cdot 2.5 \ln \frac{29.7 \overline{v}_b}{k} + \int_0^t u_f \cdot 2.5 \ln + dt \]

\[ = 2.5 u_f \ln \frac{29.7 \overline{v}_b}{k} t + 2.5 u_f (t \ln t - t) \]
or

\[ x_b t = 2.5 u_f t \left( \ln \frac{29.7 \bar{V}_b}{k} - 1 + t \ln t \right) \]  \hspace{1cm} (5.5)

Using equations (5.2) and (5.5), the equation for the bubble screen centerline is:

\[ x_b = \frac{2.5 u_f y_b}{\bar{V}_b} \left( \ln \frac{29.7 \bar{V}_b}{k} - 1 + \frac{y_b}{\bar{V}_b} \ln \frac{y_b}{\bar{V}_b} \right) \]  \hspace{1cm} (5.6)

The distribution of the vertical velocities in stagnant water is given by Charlton (equation (2.8))

\[ \frac{V}{V_{\text{max}}} = e^{-40 \left( \frac{x}{y} \right)^2} \]

In flowing water, this distribution may approximately be written:

\[ \frac{V}{V_{\text{max}}} = e^{-40 \left( \frac{x - x_b}{y} \right)^2} \]  \hspace{1cm} (5.7)

where \( x_b \) is given by equation (5.6).

Figure 5.1 describes the bubble screen shape in flowing water. This figure has been done for the following parameters:

\[ Q_0 = 0.01 \text{ m}^3 \text{ sec}^{-1} \]

\[ H = 3 \text{ m} \]

\[ u_f = 0.01 \text{ m sec}^{-1} \]

\[ k = 0.005 \text{ m} \]

\[ H_o = 10 \text{ m} \]
Figure 5.1 - Approximated Shape of Air Bubble Screen in Flowing Water.
5.3 Streamlines and Particles Movement

In order to get the streamline of a bubble screen in flowing water, it is necessary to superpose the horizontal velocity profile in the channel and the velocity field generated by the bubble screen. To get the pathlines of particles in this flow field, the settling velocity of the particles has to be superposed to this flow field. Figures 5.2 and 5.3 describe the streamline pattern for different values of flow velocity in the channel. The streamline pattern is characterized by the dimensionless number

\[
\frac{u_m}{(g \, Q_0)^{1/3}}
\]

As can be seen from the streamline pattern, the bubble screen is inefficient for stopping propagation of pollutants in flowing water, but it is possible to lift the particles in suspension and bed load to the water surface.
Figure 5.2 - Computer Streamlines in Flowing Water ($U_m = 0.1 \text{ m/s}$).
Figure 5.3 - Computer Streamlines in Flowing Water ($u_m = 0.2$ m/s).
Figure 5.4 - Air Bubble Screen With Low Velocity in the Channel.

Figure 5.5 - Air Bubble Screen With High Velocity in the Channel.
CHAPTER 6
APPLICATIONS FOR CONTROL
OF MARINA'S ENVIRONMENTAL IMPACT

6.1 Analysis of Air Bubble Screen to Prevent Surface Transport of Pollutants

Previous studies have been done about this subject. The principal was to generate surface velocity which is higher than the spreading velocity of the pollution. A different technique that requires less energy is presented.

When pollution propagates in a channel on the water surface, it is possible not only to stop it, but also to collect it, using a diagonal pipe as described in Figure 6.1. The necessary condition for the pollutants to travel along the pipe without crossing it is given in the equation:

\[ \frac{u_p u_{max} \cos \beta}{u_{max} \sin \beta} = \tan \theta \]  \hspace{1cm} (6.1)

or

\[ u_{max} = u_p \cos \theta \]  \hspace{1cm} (6.2)

where \( u_p \) is the spreading velocity of the pollution on the surface.

The pollution is carried out from the channel with a very thin layer of water, through weirs at the channel banks.
Figure 6.1 - Air Bubble Screen System to Control Surface Pollution.
The air discharge per unit length, to create surface velocity which is equal to the pollution spreading velocity is:

$$Q_0 = \frac{u_p^3 (1 + \frac{H}{H_0})}{1.46^3 \cdot g}$$  \hspace{1cm} (6.3)

and the total air discharge is:

$$Q_{T1} = Q_0 \cdot L_p$$  \hspace{1cm} (6.4)

where $L_p$ is the length of the pipe. The air discharge required to push the pollutants along a diagonal pipe is:

$$Q_0 = \frac{(u_p \cos \theta)^3 (1 + \frac{H}{H_0})}{1.46^3 \cdot g}$$  \hspace{1cm} (6.5)

and the total air discharge is:

$$Q_{T2} = \frac{L_p}{\cos \alpha} \frac{u_p^3 \cos^3 \theta (1 + \frac{H}{H_0})}{1.46^3 \cdot g}$$  \hspace{1cm} (6.6)

Comparison between equations (6.6) and (6.4) yields:

$$Q_{T2} = Q_{T1} \cdot \cos^2 \theta$$  \hspace{1cm} (6.7)

Similar technique is presented in Figure 6.2. A diagonal pipe from one bank of the channel to the other create a bubble screen which is effective for flow in both directions.
\[ \overline{V}_b = \sqrt{g \cdot H_o} \cdot 0.48 \cdot \left[ \frac{Q_o}{\sqrt{g \cdot H_o}^3} \right]^{1/6} \]  

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Basing on this equation it is possible to write:

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In which \( y_b \) is measured from the bed.

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\[ = \int_0^t u_f \cdot 2.5 \ln \frac{29.7 \cdot \overline{V}_b}{k} + \int_0^t u_f \cdot 2.5 \ln + dt \]

\[ = 2.5 \cdot u_f \cdot \ln \frac{29.7 \cdot \overline{V}_b}{k} \cdot t + 2.5 \cdot u_f \cdot (t \ln t - t) \]
or

\[ x_b t = 2.5 u_f t \left( \ln \frac{29.7 \bar{V}_b}{k} - 1 + t \ln t \right) \tag{5.5} \]

Using equations (5.2) and (5.5), the equation for the bubble screen centerline is:

\[ x_b = \frac{5 \ u_f \ y_b}{\bar{V}_b} \left( \ln \frac{29.7 \bar{V}_b}{k} - 1 + \frac{y_b}{\bar{V}_b} \ln \frac{y_b}{\bar{V}_b} \right) \tag{5.6} \]

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\frac{u_m}{(g Q_0)^{1/3}}
\]

As can be seen from the streamline pattern, the bubble screen is inefficient for stopping propagation of pollutants in flowing water, but it is possible to lift the particles in suspension and bed load to the water surface.
\[ \frac{U_M}{[gQ_0]^{1/2}} = 0.23 \]

Figure 5.2 - Computer Streamlines in Flowing Water \((U_M = 0.1 \text{ m/s})\).
Figure 5.3 - Computer Streamlines in Flowing Water \( (U_m = 0.2 \text{ m/s}) \).
Figure 5.4 - Air Bubble Screen With Low Velocity in the Channel.

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pipe as described in Figure 6.1. The necessary condition for the pol-
lutants to travel along the pipe without crossing it is given in
the equation:

$$\frac{u_p \ u_{\text{max}} \ \cos \theta}{u_{\text{max}} \ \sin \beta} = \tan \theta$$

(6.1)

or

$$u_{\text{max}} = u_p \ \cos \theta$$

(6.2)

where $u_p$ is the spreading velocity of the pollution on the surface.

The pollution is carried out from the channel with a very thin
layer of water, through weirs at the channel banks.
Figure 6.1 - Air Bubble Screen System to Control Surface Pollution.
The air discharge per unit length, to create surface velocity which is equal to the pollution spreading velocity is:

\[
Q_0 = \frac{u_p^3 \left(1 + \frac{H}{H_0}\right)}{1.46^3 \cdot g}
\]  

(6.3)

and the total air discharge is:

\[
Q_{T_1} = Q_0 \cdot L_p
\]  

(6.4)

where \(L_p\) is the length of the pipe. The air discharge required to push the pollutants along a diagonal pipe is:

\[
Q_d = \frac{(u_p \cos \theta)^3 \left(1 + \frac{H}{H_0}\right)}{1.46^3 \cdot g}
\]  

(6.5)

and the total air discharge is:

\[
Q_{T_2} = \frac{L_p}{\cos \alpha} \cdot \frac{u_p^3 \cos^3 \alpha \left(1 + \frac{H}{H_0}\right)}{1.46^3 \cdot g}
\]  

(6.6)

Comparison between equations (6.5) and (6.4) yields:

\[
Q_{T_2} = Q_{T_1} \cdot \cos^2 \alpha
\]  

(6.7)

Similar technique is presented in Figure 6.2. A diagonal pipe from one bank of the channel to the other create a bubble screen which is effective for flow in both directions.
Figure 6.2 - Air Bubble Screen System to Control Surface Pollution for Flow in Both Directions.
6.2 Analysis of Air Bubble Screen Filter to Reduce Transport of Pollutants in Suspension and Bed Load

Air bubble screens properly installed and operated at a marina entrance can reduce transport of pollutants in suspension and in bed load. This chapter represents a design method for a bubble screen filter at the marina entrance.

Figure 6.4 describes the solution suggested. The particles are lifted up to the water surface by the vertical currents. They are pushed from one bubble screen to another while being carried forward by the channel flow. Finally, they are collected by two weirs at the channel banks.

The water that flows out from the channel through the weirs is directed to a settling basin where the particles will settle down.

The distance between one bubble screen to another is suggested to be $0.5H$. After this distance the streamlines start curving down causing the particles to settle faster.

Figure 6.4 indicates the longest path of a particle in the bubble screen velocity field. The time for this particle to travel from point A to point D is approximately:

$$T = \frac{0.5H}{0.5 \frac{u_{\text{max}}}{6}} + \frac{H}{0.5 (V_{\text{max}} - V_s)} + \frac{0.5H}{0.5 u_{\text{max}}} \quad (6.8)$$

where $0.5 \frac{u_{\text{max}}}{6}$ is approximately the average velocity between points A and B, $0.5 (V_{\text{max}} - V_s)$ is the particle average velocity between B and C, and $0.5 u_{\text{max}}$ is the average velocity between C and D.

The same equation may be written:

$$T = H \cdot \left( \frac{7.0}{u_{\text{max}}} + \frac{2}{V_{\text{max}} - V_s} \right) \quad (6.9)$$
Figure 6.3 - Air Bubble Screen Filter to Reduce Transport of Pollutants in Suspension and Sed Load.
Figure 6.4 - The Longest Path of a Particle in the Bubble Screen Flow Field.
Using equations (2.12) and (2.7) for $u_{\text{max}}$ and $v_{\text{max}}$:

$$T = H \left( \frac{4.8 \left(1 + \frac{H}{H_0}\right)^{1/3}}{(g \cdot Q_o)^{1/3}} + \frac{2}{1.2 \left(g \cdot Q_o\right)^{1/3} - V_S} \right)$$

(6.10)

The length of each pipe should be:

$$L_p = u_m \cdot T$$

(6.11)

where $u_m$ is the mean flow velocity in the channel.

The total discharge is:

$$Q_T = L_p \cdot Q_o = u_m \cdot T \cdot Q_o$$

(6.12)

or

$$Q_T = u_{\text{in}} (2.24 \left(1 + \frac{H}{H_0}\right)^{1/3} Q_o^{2/3} + \frac{2 Q_o}{1.2 \left(g \cdot Q_o\right)^{1/3} - V_S})$$

(6.13)

$Q_o$ should be designed to create surface velocity which is higher than the lateral velocity fluctuations in the channel and to give reasonable value for $L_p$. 
CHAPTER 7
EXTENSION OF RESEARCH

Flow in and out the marina occurs when the water level in the sea is changing due to tide. In this chapter, a basic model is described to approximate the flow velocity generated at the marina entrance.

7.1 Open Channel Transient Flow

A marina can be modeled by an horizontal open channel in which one end is a dead-end, and at the other end the water level is changing according to the tide. One may modify this basic model by making the channel wider at certain locations as indicated in Figure 7.1.

The method of characteristics with specified time interval is presented in order to solve this unsteady state problem. The differential equations for unsteady open channel flow are:

**Momentum Equation:**

\[ g \gamma_x + \frac{\tau_0}{\sigma} - g \sin \alpha + 2V V_x + \frac{V^2}{A} A_x + \frac{V}{A} A_t + V_x = 0 \]  \hspace{1cm} (7.1)

in which \( \gamma \) is the water depth, \( V \) is the flow velocity, \( A \) is the cross-section area and \( \alpha \) is the bed slope.

**Continuity Equation:**

\[ V A_x + A_t + A V_x = 0 \]  \hspace{1cm} (7.2)

(no lateral inflow or outflow exists)
Figure 7.1 - Basic Model for Flow Velocity Approximation in the Marina.
The solution by method of characteristics yields:

for $C^+$ characteristics:

$$v_p - v_R = g \int_{y_R}^{y_p} \frac{1}{C} \, dy + \int_{t_R}^{t_p} [g (S - S_o)] \, dt = 0 \quad (7.3)$$

$$x_p - x_R = \int_{t_R}^{t_p} (v + c) \, dt \quad (7.4)$$

where $c$ is the wave celerity in the channel.

for $C^-$ characteristics:

$$v_p - v_s = g \int_{y_s}^{y_p} \frac{1}{C} \, dy + \int_{t_s}^{t_p} g (S - S_o) \, dt = 0 \quad (7.5)$$

$$x_p - x_s = \int_{t_s}^{t_p} (v - c) \, dt \quad (7.6)$$

See Figure 7.2 for definition of the points $p, s, R$.

The method of specified-time interval leads to simple algebraic equations:

for $C^+$ characteristics:

$$v_p - v_R + \frac{g}{C_R} (y_p - y_R) = g (S_r - S_o) \Delta t = 0 \quad (7.7)$$

$$x_p - x_R = (v_R + C_R) \Delta t \quad (7.8)$$
Figure 7.2 - Unsteady Open Channel Flow - Solution by Method of Characteristics with Specified Time Interval.
for \( C^- \) characteristics:

\[
V_p - V_s - g/C_s (y_p - y_s) + g (S_s - S_o) \Delta t = 0 \quad (7.9)
\]

\[
x_p - x_s = (V_s - C_s) \Delta t \quad (7.10)
\]

By linear interpolation it is possible to find the values of \( V, C \) and \( y \) for the points \( S \) and \( R \), basing on known values of \( V_C, V_B, C_C, C_B, y_C \) and \( y_B \) from previous calculations.

Solving equations (7.7) and (7.9) the solution of \( y_p \) and \( V_p \) for interior points can be found:

\[
y_p = \frac{1}{C_R + C_s} (y_s C_R + y_R C_s + C_R C_s \left[ \frac{V_R - V_s}{g} - \Delta t (S_R - S_s) \right]) \quad (7.11)
\]

\[
V_p = V_R - g \frac{y_p - y_R}{C_R} - g \Delta t (S_R - S_o) \quad (7.12)
\]

for downstream boundary condition it is necessary to solve equation (7.7) \( C^+ \) characteristic) with the boundary condition:

\[
y_p = y_o - \alpha t
\]

for upstream boundary condition equation (7.9) \( C^- \) characteristic) should be solved with the condition:

\[
V_p = 0
\]
7.2 Notes on the Computer Program and the Results

The computer program which is listed in Appendix A-4, calculates the water depth and the flow velocity in the channel as a function of time, for different sections along the channel.

The solution given in Appendix A-4 is for a channel, 2000 m long, 20 m wide, and 3 in deep. The rate of tide is 1 m in 6 hours. The flow velocity oscillates between 0.0 m/s and 0.046 m/s. One should remember that higher velocity may be generated due to winds effect. Modification of this program can be made to describe different shapes of marinas.

Two recommendations for design can be made:

1) It is possible to fit the air discharge in the bubble screen to the velocity oscillations in the channel, and in this way, to reduce the amount of energy required.

2) It is recommended to locate the bubble screen as far as possible from the channel mouth, where the flow velocity is the highest.
CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

Experimental measurements as well as analytical investigations discussed in the previous chapters have led to the following conclusions:

1. CEI water current meter was found to be a good tool for investigations in bubble screens. Flow velocity measurements can be done with good accuracy.

2. It was found possible to describe the flow field generated by a bubble screen in stagnant and flowing water by streamlines. Basing on velocity measurements and linear superposition, a computer program was built to make these streamlines.

3. The behavior of particles in the bubble screen flow field may be described by superposing the settling velocity of the particles to the velocity field.

4. A technique to control marinas environmental impact was described. A bubble screen installed at a marina entrance can stop further propagation of surface pollution and can be an efficient filter for pollutants in suspension and bed load. The advantages of the bubble screen is the low energy consumption and the capability of boats to use the channel without interference.
5. An approximation for the flow velocity at the marina entrance can be made by using the method of characteristic.
APPENDIX A-1

COMPUTER PROGRAM FOR CURVE FITTING
USING GAUSE ELIMINATION METHOD
DOUBLE PRECISION A, X, C, B, DABS
DIMENSION A(4,4), X(4), C(4)
READ, A
READ, C
READ, X
N=4
C SUBROUTINE GAUSSR WILL SOLVE N SIMULTANEOUS EQUATIONS
C OF THE FORM A*X=C, A ROW INTERCHANGE IS PERMITTED SUCH THAT A(K,K)
C WILL BE LARGEST POSSIBLE IN ABSOLUTE VALUE FROM ALL ROWS BELOW ROW
C K
N=1=N=1
DO 50 K=1,N
KPI=K+1
DO 50 I=KPI,N
DO 69 L=KPI,N
IF (DABS(A(L,K)).LE.DABS(A(K,K))) GO TO 60
DO 70 J=K,N
DJ=A(L,J)
A(L,J)=A(K,J)
A(K,J)=DJ
70 CONTINUE
T=C(L)
C(L)=C(K)
C(K)=T
60 CONTINUE
B=-A(I,K)/A(K,K)
DO 40 J=K+1,N
40 A(I,J)=B*A(K,J)+A(I,J)
50 C(I)=B*C(K)+C(I)
X(N)=C(N)/A(N,N)
DO 100 K=2,N
I=N-K+1
X(I)=C(I)
KMI=K-1
DO 90 J=1,KMI
90 X(I)=X(I)-A(I, I+J)*X(I_J)
100 X(I)=X(I)/A(I, I)
DO 110 I=1, 4
110 PRINT, X(I)
STOP
END
APPENDIX A-2

COMPUTER PROGRAM FOR STREAMLINES OF A BUBBLE SCREEN FLOW FIELD IN STAGNANT WATER
T=0
0=0. 0014394
E=2. 72
G=9. 81
H=0. 578
L=1. 2
UM=1. 46*(1. +H/10.)**(-0.333)*(G*Q)**0. 333
READ, X, Y
10 DO 50 I=1, 10
11 IF(Y. GT. H) GOTO 99
12 IF(X. LT. 0.2) THEN
13 VMAX=0. 5*(G*Y)**0. 5
14 ELSE
15 VMAX=1. 2*(G*Q)**0. 333
16 END IF
17 V=VMAX*E**(-40. *(S/Y)**2. )
18 ELSE
19 IF(Y.GT. 0. 75*H) THEN
20 V=(H/5. -4. *(Y=0. 75*H)**2. )/H)*UM+0. 5/L
21 ELSE
22 V=(UM*Y)/(6. *L)
23 END IF
24 V=V
25 END IF
26 IF(Y. GT. 0. 707*H) THEN
27 UM=UM*4.*Y/H-3. *UM
28 ELSE
29 UM=-UM*0. 172
30 END IF
31 IF(X. GT. 0. 2) THEN
32 U=-UM*X+1. 2*UM
33 ELSE
34 U=(23. 6429*(X/H)**3. -24. 005*(X/H)*82. +8. 2360*(X/H)+0. 0246)*UM
35 END IF
36 X=X+U/10
37 Y=Y+V/10
38 PRINT, X, Y
39 T=T+1
40 GO TO 10
41 99 STOP
42 END
APPENDIX A-3

COMPUTER PROGRAM FOR STREAMLINES OF BUBBLE SCREEN FLOW FIELD IN FLOWING WATER
REAL K,L,M,N
READ,0,Q,H
G=9.81
E=2.718
HO=10
UF=0.01
K=0.001

UV=(Q/(G*HO**3.0)**0.5)**(1.0/6.0)*Q.48*(G*HO**0.5
UM=2.5*UF*ALOG(10.9*H/K)
TG=UV/UM
LOOP
READ,X,Y
AT END X,Y
PRINT 5

5 FORMAT('1:','NEXT PARTICLE')
3 PRINT 10,X,Y
10 FORMAT('1:','X=',F7.3,'Y=',F7.3)
DO 20 I=1,10
C=9.0**Q**(2.0/3.0)/G**(1.0/3.0)
IF(Y.LT.C) THEN
VM=0.5*(G*Y)**0.5
ELSE
VM=1.2*(G*Q)**(1.0/3.0)
END IF
V=VM*(E**(-50*(X-Y/TG)**2/Y**3))
M=(1.46*(1.0+H/HO)**(-1.0/3.0))*(G*Q)**(1.0/3.0)
D=(2**Q.5/2)**H
IF(Y.LT.D) THEN
B=-M*(3.0-2.0*2.0*0.5)
ELSE
B=4.0*M*(Y/H-3.0/4.0)
END IF
IF(X.GT.(Y/TG)) THEN
U=B*(X-Y/TG)/(H/(2*TG)+0.45*H-Y/TG)+UF*2.5*ALOG(29.7*Y/K)
ELSE
U=B*(Y/TG-X)/(H*(0.45-1.0/(2.0*TG)))+Y/TG)+UF*2.5*ALOG(*29.7*Y/K)
END IF
X=X+U/20
Y=Y+V/20
CONTINUE
IF(ABS(X).LT.0.45*H) THEN
IF(Y.LT.1.5*H) GO TO 3
END IF
END LOOP
STOP
END
APPENDIX A-4

COMPUTER PROGRAM FOR SOLUTION
OF UNSTEADY OPEN CHANNEL FLOW
APPENDIX A-4

COMPUTER PROGRAM FOR SOLUTION OF UNSTEADY OPEN CHANNEL FLOW
A computer program for solution of unsteady open channel flow is presented. By changing the boundary conditions, large variety of problems may be solved. The program uses the method of characteristics with specified time interval for solution.

Input Data:

- \( X_L \) - length of channel
- \( B \) - width of channel
- \( z_1 \) - bank slope
- \( R_N \) - Manning's n
- \( S_0 \) - bed slope
- \( y_N \) - normal depth at steady state condition
- \( T_{\text{MAX}} \) - maximum time for computation
- \( N \) - number of reaches along the channel
- \( \text{zpR} \) - number of time increment iterations between printouts
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REFERENCES


B-77


Taylor, Sir G.I., The Action of a Surface Current Used as a Breakwater.

Tekeli, S., and Maxwell, W.H.C., "Behavior of Air Bubble Screens."
Department of Civil Engineering, University of Illinois, September 1978.