% Water\_Hammer\_Streeter\_Example (Matlab code)

% 17.05.2019. 08:51

 % Water hammer example 13.9 from Streeter [1], pages 548 to 551

 % Water hammer program, with original source code in Basic (IBM-PC)

 % System is shown in Figure 13.23

 % | |

 % | |

 % | |

 % | |========================X

 % Reservoir Horizontal pipe Valve

 % Figure 13.23

 % The system consists of a reservoir with an initial water level "Hres",

 % a horizontal pipe of length "L", inside diameter "D", and friction

 % factor "f" (constant value). At the end of the pipe is located

 % a valve with a "Product of discharge coefficient and opening area"

 % defined by the matrix CVA.

 % Code Basic (IBM-PC) is shown in [1] figure 13.24

 % Results table in [1] figure 13.25

 % The system of Figure 13.23 has an initial valve opening

 % "Cd \* A" = 0.06 m² (at time T = 0) '

 % At time intervals of CVD = 5 [s], the valve opening "Cd \* A" takes

 % the values: % 0.03, 0.01, 0.003, 0.001, 0.0005, 0.0002, 0 and then

 % remains closed. '

 % Determine system transients until a time Tmax = 40 [s], after the valve

 % begins to close. '

 % Example uses a pipe division of 4 segments (N = 4).

 % Wave velocity (celerity) A = 1200 (m/s)

 % Values for CVA are given at time intervals DCV = 5 [s]

 % Calculated values are stored in the two dimensional matrices Q and H

 % T-range: 0 to Tmax

 % Second dimension I: Index of the node position I = 1 to I = NS

 % Some row numbers from Streeter code are maintained, to facilitate the

 % comparison.

 % Equation numbers of the type (13.6.8) corresponds to the Streeter

 % theory numbering

 % Equation numbers of the type (E-15), corresponds to deducted equations

 % The equations and its boundary values are shown in

% piping.tools.net, Water hammer. Method of characteristics. Example solved using Visual Basic and Finite Differences

%:::::::::::::::::::::

clear variables;

close all;

clc;

% Constants

g = 9.80665; % [m/s²]

% 'Iniial values and counter

K = 0;

num = 0;

% ..................... Input data ...............................

% 1700.

% 1.- Reservoir height

Hres = 100; % m

% 2.- Pipe length

L = 4800; %m

% 3.- Pipe internal diameter

D = 2; %m

% 4.- Friction factor

f = 0.022; % -

% 5.- Celerity

a = 1200; % m/s

% 6.- Number of sections

N = 4; % -

% 7.- Time interval of CVA values

DCV = 5; % s

% 8.- Maximum elapsed time

Tmax = 48; % s

% 'Matrix CVA. Product of discharge coefficient and opening area

% Inputs 9 to 19

CVA(1) = 0.06; % At time = 0 s

CVA(2) = 0.03; % At time = 5 s

CVA(3) = 0.01; % At time = 10 s

CVA(4) = 0.003;

CVA(5) = 0.001;

CVA(6) = 0.0005;

CVA(7) = 0.0002;

CVA(8) = 0;

CVA(9) = 0;

CVA(11) = 0;

%........................... Help variables ...........................

% 2600:

% 'Area of pipe section

 AR = (pi / 4) \* D ^ 2;

% 'Constant for Eq (13.6.9)

B = a / (g \* AR); % Eq. (13.6.8a)

% Last node "NS", corresponds to the valve position

NS = N + 1 ;

% Segment lenght

Dx = L / N;

% Time increment DT = DX / a % Eq. (13.6.2)

DT = L / (a \* N);

% .........Two dimensional matrices H and Q with zero-values .........

% 2620

H=zeros(Tmax,NS); % H matrix Tmax x 5, with zeros

Q = zeros(Tmax,NS); % Q matrix Tmax x 5, with zeros

% ...................... Initial values ...............................

% 2700:

% Initial time "Ti"

Ti = 0 ;

% To use the time as index, since the index cannot be zero, use

T = Ti+1; % Thus, for the time = 0, T = 1

% Valve CV value at t = 0 (index 1), from input matrix CVA

CV0 = CVA(1);

% 2720

% Asignment to the matrix element H(1,1), the reservoir pressure value

% at time = 0 (index 1), at position node 1

H(1,1) = Hres; % Eq. (E-20)

% 2740

% Initial flow rate

Q0 = (Hres / (f \* L / (2 \* g \* D \* AR ^ 2) + 1 / (2 \* g \* CV0 ^ 2)))^0.5 ; % Eq. (E-15)

Q(1,1) = Q0;

% at time = 0 (index 1) and node 1

% Initial piezometric height at the valve Hvalve­\_0

% at time = 0 (index 1) and node N = NS

Hvalve\_0 = Q0 ^ 2 / (2 \* g \* CV0 ^ 2); % Eq (E-13)

% Resistance coefficient "R" per segment

R = (Hres - Hvalve\_0) / (Q0 ^ 2 \* N); % Eq (E-21)

% ........... Initial values of Q and H .............................

% at time =0 (index 1)

% Initial valies are calculated for all the nodes ( 1 to NS)

% 2900

for I = 1:NS

 Q(1,I) = Q0; % Eq (E-15)

 H(1,I) = Hres - (I - 1) \* R \* Q0 ^ 2; % Eq (E-19)

% Q and H values checked

end

% ......................Start of new calculation....................

% 3900

% K value for interpolation of CV Integer.

% Kmax: maximum K-value, corresponding to the time Tmax

Kmax = floor(Tmax / DCV);

% B = floor(A) rounds the elements of A to

% the nearest integers less than or equal to A

% 3901

while T< Tmax

 num = num +1;

 T = T + DT;

Tant = T-1;

% where T is the time of new calculated term

% and Tant is the previous time ( corresponding to terms already known)

% K value for interpolation of CV Integer.

K = floor(T / DCV) + 1 ; % Eq. (H-1)

% ..... CV value is interpolated in each group of DCV seconds .....

% It corresponds to the previous tiem Tant.

% 4100

CV = CVA(K) + (Tant - (K - 1) \* DCV) \* (CVA(K + 1) - CVA(K)) / DCV ; % Eq. (H-2)

% ......... Boundary condition at the valve (node NS).............

% 4200

% Flow rate and piezometric height at the valve (node NS).

% Previous node:N

% CP and BP values at (T,NS)

CP = H(Tant,N)+ B\*Q(Tant,N); % Eq. (G-5) Eq(13.6.11a

BP = B + R \* abs(Q(Tant,N)); % Eq. (G-6) Eq(13.6.11b)

% Q(T,NS) and H(T,NS)

Q(T,NS) = -g \* CV^2 \* BP + ((g \* BP \* CV^2)^2+ CV^2 \*2\*g \*CP)^0.5 ; % Eq. (G-4)

H(T,NS) = CP - BP \* Q(T,NS) ; % Eq. (G-3)

%......... Boundary condition at the reservoir .....................

% 4600

% The value of H at the reservoir (node 1), at any time,

% is already defined as

H(T,1) = Hres; % Eq.(E-20)

% Flow rate at the reservoir at a time T

Q(T,1) = (H(Tant,1)-H(Tant,2)+ B \* Q(Tant,2)) / (B + R \* abs(Q(Tant,2))); % Eq.(F-4)b

%........ Interior sections .......................................

% 4800

% Whewn calculating a term of a node I, the term to the link of it

% has and index "I-1" and it is denoted as Ilink

% Similarly, the term of the right of it has an index "I+1" and it is

% denoted as Iright

for I = 2:N % I = 2:N

 Ilink = I-1;

 Iright = I+1;

 CP = H(Tant,Ilink) + B \* Q(Tant,Ilink); % "Changed % Eq(13.6.11a)

 BP = B + R \* abs(Q(Tant,Ilink)); % Eq(13.6.11b)

 CM = H(Tant,Iright) - B \* Q(Tant,Iright); % Eq(13.6.12a)

 BM = B + R \* abs(Q(Tant,Iright)); % Eq(13.6.12a)

 Q(T,I) = (CP - CM) / (BP + BM); % Eq(13.6.15)

 H(T,I) = CP - BP \* Q(T,I); % Eq(13.6.16)

end

end % goto 3901 to continue the while loop

 % This loop will exit when T > Tmax

%........ Print flow rates or piezometric heights .................

 T = linspace(1,Tmax,Tmax);

 % \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 % Column with piezometric heights of node 5

 % H(T,5)

 %\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 % Column with flow rate of node 3

 % Q(T,3)

 %\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 % Matrix with piezometric heights of all nodes

 plot(T,H(T,1), T,H(T,2),T,H(T,3), T,H(T,4), T,H(T,5))

 %\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 % Plot of flow rates of all nodes

 % plot(T,Q(T,1), T,Q(T,2), T,Q(T,3), T,Q(T,4), T,Q(T,5))

 %\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

 % Program end

 % References

 % [1] Mecánica de fluidos

 % Victor L. Streeter and E. Benjamin Wylie

 % 8th edition, 3rd in spanish