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DEVELOPMENT OF SOURCE CODE FOR HARDY CROSS METHOD IN C#.NET FOR WATER DISTRIBUTION NETWORK

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Abstract:-As water distribution networks have been a part of the modern living, it is necessary to know the behavior of a water distribution network under different conditions. There are different methods of pipe network analysis but most of the methods are very complex and hence time consuming to find out the desired results manually. The Hardy Cross method is simple, easy to apply, and therefore, suitable for hand calculation. However, the Hardy Cross method converges slowly hence requires large number of iterations. The number of iterations increases enormously as the size of the network increases. Therefore, it is necessary to develop the source code for Hardy Cross method to balance the pipe network. The source code was developed in C#.NET which has many advantages over other languages such as Consistent Programming Model, Direct Support for Security, Simplified Development Efforts, Easy Application Deployment and Maintenance, .NET Framework and Languages and cross-language compatibility.

Keywords: Water distribution network, pipe network analysis.

INTRODUCTION :-

Next to air, water is the most essential commodity required to maintain life. The present uses of water are varied and may be classified as domestic, public and industrial. A modern water supply system includes facilities for collection and storage, transportation, pumping, treatment and distribution of water. Distribution works include distribution and equalizing reservoirs, pipes, valves, fire hydrants and other appurtenances. Water distribution networks have been a part of the modern living.

Out of the total expenditure incurred on different facilities of water supply system, major expenditure is incurred on the distribution network. Therefore, it is necessary to know the behavior of a water distribution network to optimize and economize its operations under different conditions such as variation in demand including fire flow requirements, variation in reservoir water levels, partial or full valve openings, closure of pipes during repairs or replacement. The behavior of a water distribution network under different conditions is obtained by carrying out the analysis of the water distribution networks.

In addition to these, analysis of the system is necessary to know whether the capacity of the source or sources is adequate, whether the available storage capacity and water levels in the service reservoirs at different points of time are satisfactory, whether the system has adequate residuals heads at different locations.

There are different methods of pipe network analysis such as Hardy Cross method, Newton Raphson method, Linear theory method and Minimum-Spanning-Tree Approach but these methods are very complex and hence time consuming to find out the desired results manually. The Hardy Cross method (1949) is simple, easy to apply, and therefore, suitable for hand calculation, however, its greatest drawback is the presence of the convergence problem. It is observed to converge slowly and therefore requires large number of iterations. The number of iterations increases as the size of the network increases. Therefore, it is necessary to develop the source code for Hardy Cross method to balance the pipe network.

REVIEW OF RELATED LITERATURE:

Volokh (2002) showed that the Hardy Cross moment-distribution method is Jacobi iterative scheme applied to the standard displacement formulation of structural analysis. He also showed that the stiffness matrix enjoys strict diagonal dominance and because of it the iterations always converge for any loading conditions.

Jeng (2002) proposed a general model for an urban drainage system through the Newton-Raphson method, which allows users to calculate the pipe system with arbitrary pipe network. Based on this proposed model, a design for pipe geometry (including length, diameter, pipe materials) can be provided for given inlet and outlet flow conditions. This will provide hydraulic engineers a simple guideline for the design of an urban drainage system.

Lopes (2003) developed user-friendly software for the calculation of general piping system networks composed of virtually any parallel and series pipe arrangement. Solution of the network is made with recourse to the iterative method of Hardy Cross. Solution is provided for pressure and flow-rate in each branch. Dimensioning problems, where pump characteristics or a pipe diameter are sought for achieving a pre-specified flow-rate condition, can also be tackled.

Ohtmer (2005) applied Newton-Raphson iteration procedure for the analysis of nonlinear flow in pipe networks. Pipe networks are computed in an analogous manner to frameworks in structural mechanics loaded only by moments. The mesh method (force method) is applied. Due to the boundary layer effects in special pipe members, the flow problem is in general nonlinear. Therefore, the Newton-Raphson iteration procedure is used to solve the nonlinear system of equations. Using the computed flow rates in the TREE structure (determined by graph theory) as initial values, the iteration procedure converges rapidly to a user specified tolerance value. The loss coefficients of pressure for different pipe members (Tube, Valve, Bow, Tee, Pump, Knee, ±Contr, ±Difsr) need only be given in diagrams. These diagrams are used in digitalized form. In the back-substitution phase with known flow rates in all members, the pressure at the joints is computed. The main advantages of the analysis as outlined are that no initial values for the member flow rates need be known, the iteration procedure converges rapidly, and within each iteration step only small systems of linear equations need to be solved. Due to the fact that the loss coefficients of pressure need only be given in diagrams, arbitrary nonlinear networks can be analysed by the unchanged program system. A flow rate assumption may be specified in the input for a member of a mesh.

Ormsbee (2006) presented a brief historical review of various methods for computing flows and pressures in water distribution networks from the middle of the 19th century through the dawn of 21stcentury. According to him, this era has witnessed the development of several innovative methods for network analysis, including such methods as the Hardy Cross method, and the application of the Newton Raphson method to various formulations of the conservation of mass and conservation of energy equations associated with water distribution networks. With the advent of greater knowledge about the physical, chemical, and biological characteristics of water distribution systems, as well as the advent of new computer algorithms and associated computer technologies, the future opportunities for even greater impacts remain bright.

Zyl et.al.(2008) proposed a new method for "snapshot" analysis of water distribution systems based on the commonly used gradient method. The proposed method uses a secant (intersecting the head-loss function in two points) instead of a tangent to approximate the pipe head-loss function. They developed a theoretical model for the flow range in which the secant approximates the head-loss function without exceeding a given allowable error. This scheme allows a tradeoff to be made between the allowable error and the number of iterations required to achieve convergence. The proposed method was applied to an example network to illustrate its application and benefits. They argued that the number of iterations required to find a solution can be reduced significantly in both snapshot and extended-period simulations. Thus, the literature shows that Hardy-Cross method has been widely used. Many researchers have modified the Hardy-Cross algorithm to improve its computational efficiency.

Materials and Method:

Hardy Cross Method:

Hardy Cross method is method of successive approximations and is used to solve the pipe network problems. The procedure for the solution of pipe network problems by Hardy Cross method is as follows;

1.Assume a most suitable distribution of flow that satisfies principle of continuity at each junction.
2.With the assumed values of discharge (Q), compute the head losses for each pipe by using Darcy-Weisbach equation.
3.Compute the net head loss around each loop considering the head loss in clockwise flows as positive. And in anti-clockwise flows as negative. For a correct distribution of flow, the net head loss around each loop should be equal to zero.
4.If the net head loss around the loop is not zero for the assumed distribution of flow, the assumed flows are then corrected by introducing a correction ΔQ for the flows till the loop is balanced. The correction ΔQ is given by

$$\Delta Q = \frac{\sum rQ|Q|}{\sum 2r|Q|}$$

5With the correction factorΔ Q, the new discharge in each pipe is calculated as follows:
New discharge (Q) = Old discharge (Q) +Δ Q
6With the corrected flows in all pipes, a second trial calculation is made for all the loops and the process is repeated till the corrections become negligible.

DESCRIPTION OF SOURCE CODE:

Source code in C#.NET for Hardy Cross method was developed for two loop pipe network which can be applied for the pipe network containing any number of loops. The C#.NET was preferred to develop the source code because it has the following Advantages

Consistent Programming Model
Direct Support for Security
Simplified Development Efforts
Easy Application Deployment and Maintenance
.NET Framework and Languages
Cross-language compatibility

The data type declarations

The C#.NET version has decimal keyword equal to 128-bit data type. The approximate range and precision for the decimal type are -1.0 X 10-28 to 7.9 X 1028 whereas other languages have the 32-bit data type only. Because of 128-bit data type we get the precise results in C#.NET for any type arithmetic and numeric calculations. The flowchart for which the source code was developed, is shown in figure1.

Hardy-Cross Flow-Chart

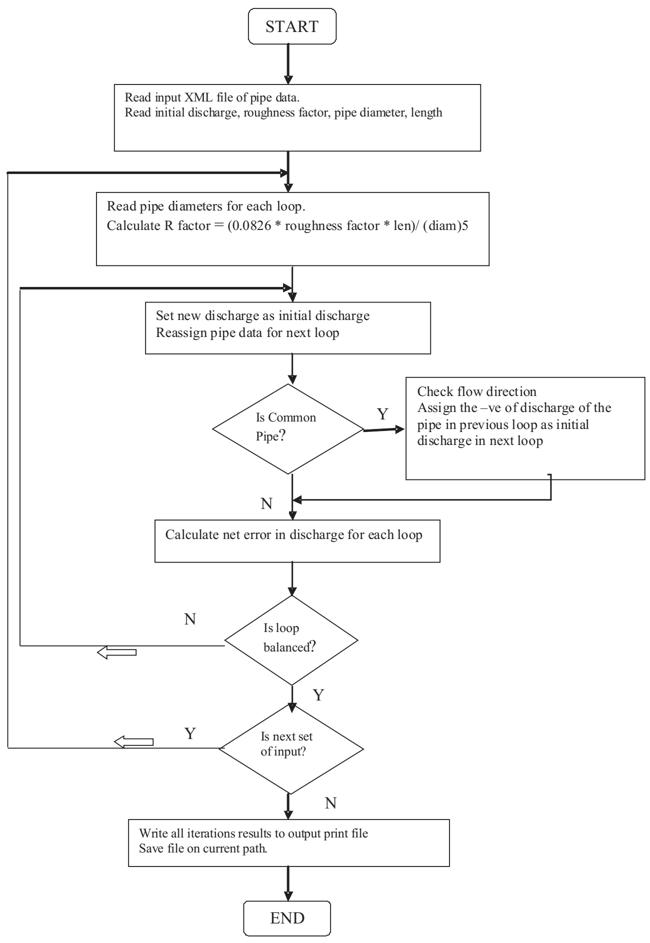

Fig.1 Flow chart of the Hardy Cross method

RESULTS AND DISCUSSION

The two loop pipe network was considered to develop the source code in C#.NET for Hardy Cross method. The source code was developed for the single set of diameters. The results generated are presented below:

Iteration 1

Loop	pipe	No	r	Q_0	$rQ_0abs(Q_0)$	$2rabs(Q_0)$	Delta Q	New dis
1	AB	1	253.75	0.120	3.65	60.90		0.1347
	BE	2	8260.00	0.010	0.83	165.20		0.0247
	EF	3	3263.21	-0.060	-11.75	391.59	0.0147	-0.0453
	FA	4	258.13	-0.100	-2.58	51.63		-0.0853
				SUM =	-9.85	669.31		
2	BC	5	13056.79	0.0500	32.64	1305.68		0.0472
	CD	6	3263.21	0.0100	0.33	65.26	-0.0028	0.0100
	DE	7	8260.00	-0.0200	-3.30	330.40		-0.0200
	EB	8	33050.00	-0.0247	-20.16	1632.67		-0.0247
				SUM =	9.50	3334.01		

Iteration 2

Loop	pipe	No	r	Q_0	$rQ0abs(Q_0)$	$2rabs(Q_0)$	Delta Q	New dis
1	AB	1	253.75	0.1347	4.61	68.37		0.1334
	BE	2	8260.00	0.0247	5.05	408.29		0.0234
	EF	3	3263.21	-0.0453	-6.69	295.55	-0.0013	-0.0466
	FA	4	258.13	-0.0853	-1.88	44.03		-0.0866
				SUM=	1.08	816.24		
2	BC	5	13056.79	0.0472	29.03	615.63		0.0421
	CD	6	3263.21	0.0100	0.33	32.63	-0.0050	0.0050
	DE	7	8260.00	-0.0200	-3.30	165.20		-0.0250
	EB	8	33050.00	-0.0234	-18.10	773.37		-0.0284
				SUM =	7.95	1586.83		

Iteration 3

Loop	pipe	No	r	Q_0	$rQ_0abs(Q_0)$	$2rabs(Q_0)$	Delta Q	New dis
1	AB	1	253.75	0.1334	4.51	67.69		0.1334
	BE	2	8260.00	0.0234	4.52	386.41		0.0234
	EF	3	3263.21	-0.0466	-7.09	304.19	0.0000	-0.0466
	FA	4	258.13	-0.0866	-1.94	44.71		-0.0866
				SUM=	0.01	803.01		
	BC	5	13056.79	0.0421	23.18	550.20		0.0421
2	CD	6	3263.21	0.0050	0.08	16.28	0.0000	0.0050
	DE	7	8260.00	-0.0250	-5.17	206.60		-0.0250
	EB	8	33050.00	-0.0234	-18.10	773.37		-0.0234
				SUM =	0.00	1546.44		

In above iterations, r is roughness factor of the pipe, Q_0 is initial discharge in the pipe (m^3/s). It was observed that the Hardy Cross method converged in iteration 3.

CONCLUSION

The source code for the Hardy Cross method was developed for the single set of diameters in the two loop network. The source code can be generated for more than one set of diameters when the cost of the network is to be optimized by using the optimization techniques such as genetic algorithm where the population of all possible solutions needs to be generated.

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